

Projektarbeit

High resolution precipitation intensity: measurement and analysis



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1. Introduction

In August 2005 severe floods affected wide regions of Switzerland causing 6 dead and damages of about 3 billion Swiss francs. The conducted event analysis [1] indicated among others that the accuracy of the predictions suffers from an insufficient consideration and a poor understanding of the small scale variability in space and time of different processes and their interactions.

In order to ameliorate these predictions, the project APUNCH (Advanced Process Understanding and prediction of hydrological extremes and Complex Hazards) focuses on the path of a water drop from its formation to its end destination. Concretely, this multidisciplinary project deals with atmospheric and precipitation processes, sediment transport mechanisms, and hydraulic as well as geotechnical processes.

Concerning the precipitation, this project aims at investigate the temporal and spatial structure of rainfall in mountainous regions. For this purpose, a X-Band radar was installed at the Klein Matterhorn in the Visp valley. In order to calibrate and validate the measurements performed by this radar, rain gauges with high temporal resolution are necessary. Moreover, thanks to smaller stations connected to a “main” rain gauge, it will be possible to analyze the small scale variance of precipitation.

The goal of this Projektarbeit is to present and assess the performance of the device that will be used as “main” rain gauge. On the first part of this work, a small user manual will briefly present how to use the gauge and the different delivered programs. Secondly, different tests on the measurements provided by the gauge will be conduct. They will improve the general understanding of the gauge and allow as well to assess and test the accuracy of the different sensors. In the last part of this Projektarbeit, the data provided by the gauge will be analysed with scaling based methods. Looking at different types of data set, a particular interest will be paid to the non-power-law-scale properties in time of rainfall.

2. User Manual of the TRwS

The following manual is based on the already existing user's guide provided with the gauge (ver. 3.1). It tries to describe in a more detailed way some features of the rain gauge TRwS (Total Rain weighing Sensor). First, the installation of the different mechanical elements of the rain gauge will be shortly presented. After that, the role of the different electronic components will be explained. In a further part, the different data provided by the gauge as well as the way to recuperate it will be briefly presented for the both possible temporal resolutions. Indeed the gauge can provide data each 5 seconds when it is directly connected to a computer. On the contrary, when the data transit through the data logger, the measurements are sent to a server with a resolution of 1 minute. Finally, a presentation of the terminal that allows dialoguing either with the rain gauge or with the data logger will be made.



Warning



If you don't want to spend time to read the following treasure of literature, just remember to **ALWAYS set the white plastic transport rest during each manipulation** that could induce shock on the strain gauge bridge (transport and emptying or installing manipulations). More information concerning this transport rest is available in the chapter 2.2.2

2.1 General points

Different types of rain gauges are available to measure the precipitation intensity. The final report about WMO laboratory intercomparison of rainfall intensity gauges [2] proposes a detailed classification and description of different available type of rain gauges. To summarize, there are two main types of rain gauges: the catching and the non-catching instruments. The first group measures the water equivalent volume or mass of the precipitation falling through an orifice of precisely known dimension. The intensity is derived considering the amount of accumulated precipitation during specified laps of time. The non-catching instruments measure for example the drop size distribution and the velocity of falling particles and can thus calculate the rainfall intensity or amount by mathematical integration. The table 1 tries to highlight the most important characteristics of the different rain gauges types.

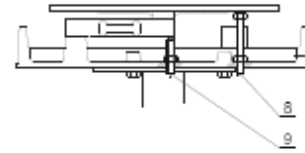
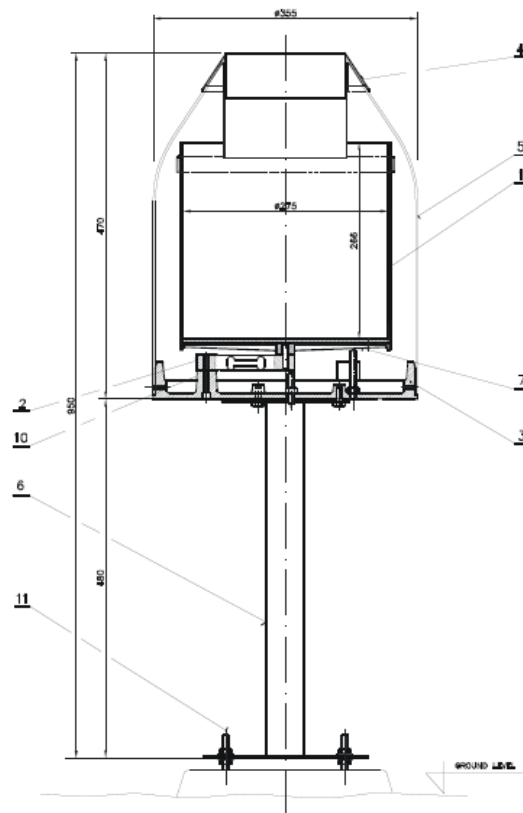
Table 1 The different rain gauges types

	Type	Measuring element	particularity
catching	Tipping bucket rain gauges	There is a tipping balance with two buckets. Each tip produces an impulse. The intensity is calculated over the period of time between 2 tips.	They generally suffer from systematic non linear errors amounting up to 20% for high rainfall intensities. These errors can be strongly reduced thanks to software or mechanical corrections.
	Level measurement rain gauges	The water is collected in a tube of specified diameter. The water level provides information about the volume.	The water level can be measured with any desired temporal resolution.
	Weighing rain gauges	Without funnel: the precipitation is directly collected into a bucket and weighed, thanks for example to a tensiometer. With funnel: the water is first collected in a funnel that fills a cylinder whose weight is determined.	Without funnel: there is noise in the weight measurement due to different perturbations. This noise has to be filtered by software, involving thus a delay of 1 to 10 minutes in the output. With funnel: there are wetting losses involving a delay for the residual water. The solid precipitation has first to melt.
	Drop counters	These instruments use a thin nozzle in order to produce single uniform droplets, which are counted by an optical system.	The thin nozzle requires a lot of attention for the field operation. It is therefore more used for research purposes.
Non-catching	Impact disdrometers	A membrane of plastic or metal is used as measurement surface to sense the impact of single precipitation particles.	Little knowledge is available on the attainable measurement uncertainty of these devices.
	Optical disdrometers	One or two thin laser light sheets detect particles crossing it. Each particle blocks the transmitted light intensity to an amount proportional to its diameter.	As for the impact disdrometers, little knowledge is available. Moreover the calibration of this device is really difficult.

The TRwS is a weighing rain gauge without funnel produced by the company MPS from Slovakia. It is able to indicate as well the liquid as the solid precipitation with a resolution of 0.001 mm and an accuracy of 0.1%. In addition, sophisticated data algorithms eliminate the undesirable effects in the weight measurements due to the wind, the evaporation or the temperature influence. Moreover, unreal step changes of weight are also eliminated.

2.2 Description and installation of the mechanical part

The TRwS consists of the following parts:



1. Bucket
2. Strain-gauge bridge
3. Base plate with box for electronics
4. 200 cm² orifice – collecting ring with heating
5. Housing
6. Pedestal
7. Support plate
8. 3x adjustable screw bolts
9. Adjustable transport screw bolt
10. Support of sensor
11. Adjusting screw bolts between the pedestal and the guying base

Figure 1 Mechanical construction of the TRwS 200. Source: User's Guide ver. 3.1

2.2.1 Required material

For the installation the following “tools” are necessary:

- a thin screwdriver (also indispensable to change the place of the wires, see the point 1.3.6)
- two keys 13.
- a level.

Moreover, the following additional elements should be as well not forgotten. Because the heating ring of the gauge is quite energy consuming (max. 2A), it is necessary to be connected to the electrical network. It is thus indispensable to take a European – Swiss plug adapter for each rain gauge. It is as well important to use antifreeze liquid for an optimal utilisation during the winter. Common antifreeze liquid should be appropriated. For the data transmission, a sim card is logically required. Specific indications concerning the sim card installation are available in chapter 2.3.2 and 2.6.1.

If an intervention on the field is necessary, for example in order to change certain parameters, it is important to check that the computer that will be used to make these changes has the

good cable connections possibilities. Otherwise adequate converters are necessary. For more information see the chapter in 2.3.3 and 2.6.1.

2.2.2 Installation

For this testing phase, instead using a base, a metallic stake was pressed in the ground. The pedestal was stabilised on this stake, thanks to different “wood flakes”. On this way, a very good stability of the rain gauge was guaranteed.

Once this pedestal is installed, the base plate can be set on it. For the precision of the measurement it is absolutely necessary that this base plate is set perfectly horizontal. Thanks to the 3 different adjustable screw bolts (see figure 2) it is really easy to do.



Figure 2 One of the adjustable screw that fix the base plate on the pedestal.

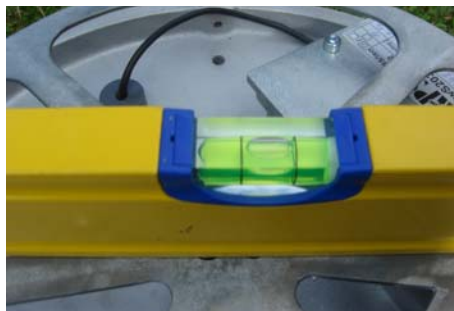


Figure 3 The level tool.

Use the level tool at least in two different directions to ensure that the horizontality is perfect. Proceed in an iterative way with the level tool (see figure 3). When it is horizontally in one direction, recheck in the other one. Or simpler, use a circular level tool, able to directly indicate the horizontality in all directions. When it is satisfactory, block the base plate, gripping the different bolts.

The strain gauge that measures the total weight of fallen precipitation is installed on this base plate. This sensor is very sensitive, so that in order to avoid any damage during transport, it is necessary to introduce the transport rest under the strain gauge bridge, as shown in the figure 4. Also after emptying operation or every time that the bucket is placed on the support plate, it would be better to insert as well the transport rest.



Figure 4 The white transport rest is introduced under the strain gauge.

When the base is correctly installed on the pedestal, just set the bucket on the support plate and install the white housing. For the installation of the housing, it is important to control that the heating wire is connected to power supply through the two little metallic stems. At the end, when all is set, the three lateral screws outside must be gripped in order to stabilise the housing to the base.

2.3 Description of the electronic part

All the electronic part is installed in a little white box, that isn't water proof. For the further tests that will be made in Payerne and Zermatt, the electronic components are installed in a water proof box. It was successfully checked that the gauge was still able to send data trough GPRS inside this box.

The different electronic devices are briefly presented, beginning from the right of the figure 5.

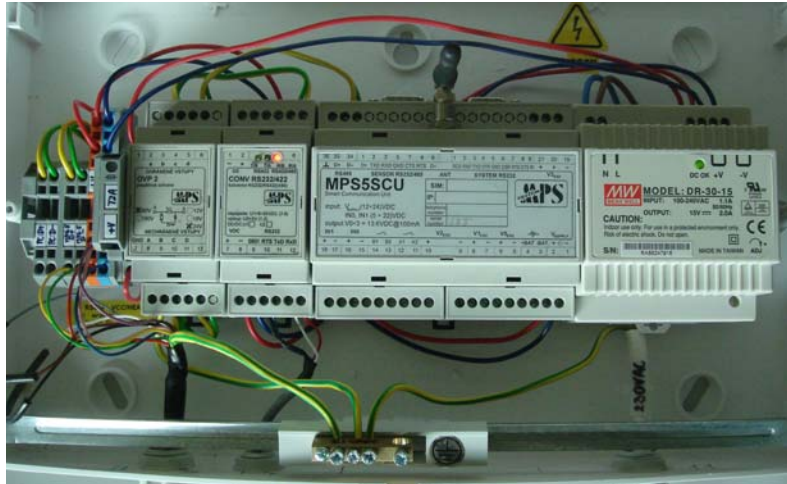


Figure 5 Picture of the box and its different parts.

2.3.1. DR 30-15

This component is a power supply able generating a precise output of 30 Watt and 16V from different input ranges. It is connected to the electrical network through the big white cable. For more technical detail such as for example a complete description of the output, the range of allowed input or the limit operating conditions, all the characteristics of this element are presented here: <http://www.meanwelldirect.co.uk/product/DR-30-15/DR-30-15/default.htm>

2.3.2. MPS05 CPU



Figure 6 The place where the sim card must be inserted.

It is the central processor unit. It collects the measurements from the connected sensors and can send it for example via GPRS to a server. It works thus as data logger and modem.

To send the data through GPRS a sim card must be inserted “behind” the data logger (See figure 6). To separate the data logger from its metal bar support, pull on the little black ring. For further information concerning the sim card and the data logger, see the part 2.6.1 or consult the file MPS05CPU.pdf that is located at: \TRWS_manual\MPS05CPU_logger.

2.3.3. CONV RS232/422

It is an analogue-to-digital converter. This device is necessary because the sensors produce analogue signals for example in the form of voltage. These analogue signals must be first converted in digital signals before that they can be used by a computer or the data logger.



Figure 7 The female part ending of the 9 pin junction cable DB9.

To read the data with 5 seconds resolution, the gauge must be directly connected to a computer through the grey cable going out from the converter. It is a 9 pin junction cable (see figure 7). Pay attention to have a such connection possibility on the computer or a adequate USB converter.

2.3.4. OVP2

This part is an Over Voltage Protection device, protecting thus the other components from too high voltage on the power supply line.

2.3.5 Fuse

This little and thin grey component is a device providing protection to the other components if an uncontrollable amount of current flows. In this case, the fuse would melt breaking thus the path of current flow. After that a new fuse has to be installed. For that it is just necessary to unplug the grey box pulling on the little grey handle (See picture 8).

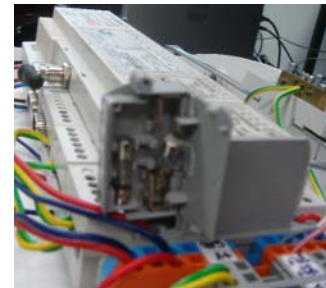


Figure 8 The fuse inside the grey box.

2.3.6. Multiconnector

This part is composed from different single connectors. To send the measurements via GPRS, the data have to transit through the data logger, and thus the yellow and green wires should be connected on the places MPS5 D+ and D-. To have directly the data with a computer, just connect these two wires on the PC D+ and D- places (See figure 9). For this purpose, just take a thin screwdriver and place it on the hole behind the cable and do a little lever movement on your direction. During the manipulation, it is not necessary to take any precaution such as unplugging the gauge. Logically because of these two different places, it is not possible to have in the same time the 5 seconds and the 1 minute data resolution.

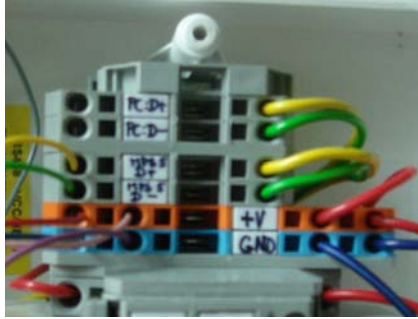


Figure 9 The multiconnector. Left: the different wires (6) coming from the gauge.

On the figure 9, other wires are also present. The cable of the rain gauge arrives indeed to the multiconnector with 6 wires. This 50m long cable is a prolongation of the original rain gauge cable. Unfortunately the wires of this additional cable don't have the same colours as the original one. The table 2 presents the different wires.

Table 2 The different wires coming from the rain gauge.

description	Colour (original cable)	Colour (Additional cable)
Positive supply power Vcc	red	brown
Negative supply power GND	blue	white
Positive heat power Vheat+	pink	pink
Negative heat power Vheat-	violet	grey
Positive data D+	yellow	yellow
Negative data D-	green	green

Note that the additional cable contains a black wire that is empty and thus useless. Other wires link different elements of the electronic systems. The table 4.1 in the original user's guide v.3.1 describes these other wires.

2.4. Data provided with a temporal resolution of 5 seconds

This resolution is available when a computer is directly connected to the rain gauge (see points 2.3.3 and 2.3.6).

To collect and see in real time the data provided by the gauge with a temporal resolution of 5 seconds, the program Universal Sensor Manager (usm) must be used. It is located in the directory: ...\\MPS-tools\\usm\\ETH-APS. Note that the data is collected only when this program is running, otherwise the data sent by the gauge will be neither collected nor stored.

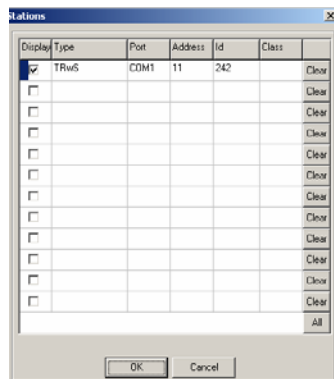


Figure 10 The address per default of the station is 11. To set a new address see point 2.6.2

In the per default configuration only 4 different measurements are graphically represented. It is possible to select in the “config” menu other or more data. It is as well good to increase in the “settings” menu (see figure 11) the maximum and optimum values (for example 1200 and 1100) otherwise only the measurements of the two last minutes are visible on the graph. Note that all these changes have to be done before clicking on “new”, otherwise they will not be applied.

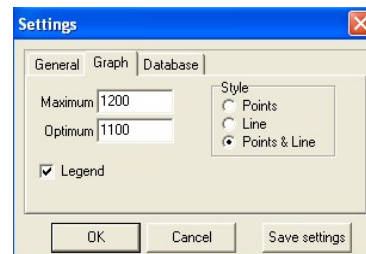


Figure 11 The settings menu

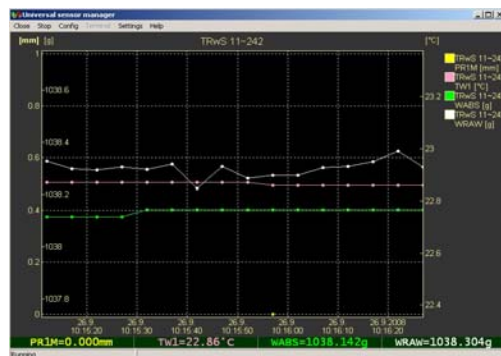


Figure 12 Measurements with 5 second resolution

With a “double-click” on usm.exe, two different windows will be opened. In the “universal sensor manager” one, click on “new”. This will open another window proposing a choice of station. In this case just one station with the following characteristics is available (see figure 10).

To start collecting the data, click on the ok button. The measurements will be graphically presented in real time with a resolution of 5 seconds.

The figure 12 presents the graphic of the measurements obtained with the default configuration. The grey value WRAW represents the raw weight measured by the gauge. This value is derived from 120 other measurements (24 measurements pro second). It has a very fluctuating behaviour, because of the high sensitivity of the weight sensor.

The MPS Company developed a lot of complicated algorithms in order to filter these variations, produced for example by the wind or temperature fluctuations or other perturbations. After this treatment the green WABS value is obtained. This absolute weight value presents logically a more stabile behaviour over time. The pink data represents the sensor temperature and the yellow one the one minute intensity that is directly derived from the weight changes. 1 mm rain corresponds to 20 gram water. It is logical regarding at the 200 cm² of the orifice. In this case, the absolute weight represents a rather conservative value of the weight, but it doesn't play for the calculation of the intensity, because only the changes of weight are taken into account.

As already mentioned, the rain gauge provides in fact more data. On the other window usm.exe, all the data transmitted by the rain gauge is indicated (see figure 13). The program usm send (S) a request about each 5 seconds to the rain gauge (address 11). The response (R) contains all the measurements done by the rain gauge.



Figure 13 The usm.exe window.

All these data are also stored in a separate text file under the directory ...\MPS-tools\usm\ETH-APS\data. Every time that the program usm is started, a new file is created. It contains only the measurements made during the time when the program was running. The name of the file indicates when began the measurement. (data10242_yyyymmddhhmm). It is possible to open and close this text file (not the program) during the measurements without any precaution, the text file is automatically updated.

Let put an object in the gauge to simulate a pulse of precipitation in order to better present all the different data provided by the rain gauge.

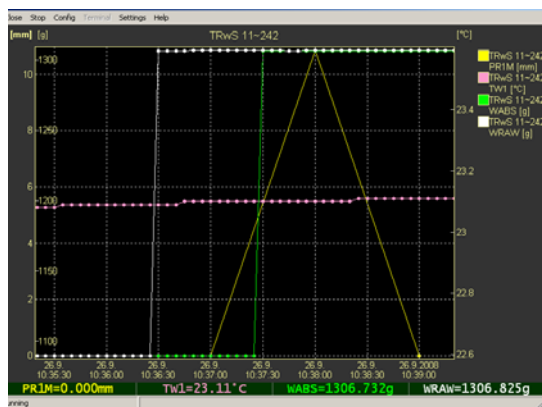


Figure 14 simulation of a pulse rainfall

The object was placed between 10:36:25 and 10:36:30 in the gauge. Note that the indicated time is the one from the clock of the computer, so check that it is right. Logically, the raw weight reacts directly to this input. On the contrary, the absolute weight reacts one minute later at 10:37:30, because of the delay involved by the different filter mechanisms. The gauge indicates an intensity of about 11mm for the minute between 10:37 and 10:38. It represents thus a delay of 1 minute, because in the reality this input occurred between 10:36 and 10:37.

The table 3 presents all the recorded data for the example of the pulse rainfall simulation.

Table 3 data of the text file related to the pulse rainfall simulation

	1min prec	1min rain duration	Sensor temp	Total weight	Statistic number id	Devi ation	Internal time	Raw weight	Base weight	Comp arated weight	Ext temp	Weight noise
	PR1M	RD1M	TW1	WABS	STATID	DEV	TIME	WRAW	WBEGIN	WCOMP	TA1	WNOIS
	mm	s	°C	g	-	-	hms	g	g	g	°C	g
10:36	-	-	23.09	1089.715	2	0	171809	1089.83	1089.712	1089.712	23.7	0.066
10:36	-	-	23.09	1089.715	2	0	171814	1089.864	1089.712	1089.712	23.7	0.066
10:36	-	-	23.09	1089.715	2	0	171819	1089.806	1089.712	1089.712	23.7	0.066
10:36	-	-	23.09	1089.715	2	0	171824	1089.794	1089.712	1089.712	23.7	0.066
10:36	-	-	23.09	1089.715	2	0	171829	1089.952	1089.712	1089.712	23.7	0.066
10:36	-	-	23.09	1089.715	1	0	171834	1306.681	1089.712	1089.712	23.7	0.066
10:36	-	-	23.09	1089.715	1	0	171839	1306.762	1089.712	1089.712	23.7	0.066
10:36	-	-	23.09	1089.715	1	0	171844	1306.75	1089.712	1089.712	23.7	0.066
10:36	-	-	23.1	1089.715	1	0	171849	1306.751	1089.712	1089.712	23.7	0.066
10:36	-	-	23.1	1089.715	1	0	171854	1306.835	1089.712	1089.712	23.7	0.066
10:36	-	-	23.1	1089.718	1	0	171859	1306.779	1089.712	1089.712	23.7	0.066
10:36	0	60	23.1	1089.718	1	0	171904	1306.823	1089.712	1089.712	23.7	0.066
10:37	-	-	23.1	1089.718	1	0	171909	1306.843	1089.712	1089.712	23.7	0.066
10:37	-	-	23.1	1089.718	1	0	171914	1306.843	1089.712	1089.712	23.7	0.066
10:37	-	-	23.1	1089.718	1	0	171919	1306.831	1089.712	1089.712	23.7	0.066
10:37	-	-	23.1	1089.718	1	0	171924	1306.832	1089.712	1089.712	23.7	0.066
10:37	-	-	23.1	1089.718	1	0	171929	1306.802	1089.712	1089.712	23.7	0.066
10:37	-	-	23.1	1306.732	1	0	171934	1306.838	1089.712	1089.712	23.7	0.058
10:37	-	-	23.1	1306.732	1	0	171939	1306.803	1089.712	1089.712	23.7	0.058
10:37	-	-	23.1	1306.732	1	0	171944	1306.828	1089.712	1089.712	23.7	0.058
10:37	-	-	23.1	1306.732	1	0	171949	1306.73	1089.712	1089.712	23.7	0.058
10:37	-	-	23.1	1306.732	1	0	171954	1306.755	1089.712	1089.712	23.7	0.058
10:37	-	-	23.1	1306.732	1	0	171959	1306.868	1306.732	1306.732	23.7	0.124
10:37	10.9	60	23.1	1306.732	1	0	172004	1306.821	1306.732	1306.732	23.7	0.124

The first column of this table represents the time of the related records. In the text file the seconds are indicated. Even if it is 5 seconds resolution data, the rainfall intensity (PR1M) is indicated only each minute, because of the time needed by the different algorithms to treat the raw data. The rain duration (RD1M) in the third column indicates logically 60 seconds because no sensor for rainfall detection is installed with this gauge. Otherwise it could detect when the rain began and indicates the duration of the rain during the minute. The sensor temperature (TW1) as well as the external temperature (TA1) are also available each 5 seconds. There are many measurements of the weight. The raw weight (WRAW) presents logically the higher variations. The Total Weight (WABS) is updated every 25 and 35 seconds. As already mentioned it reacts with a delay of 1 minute. The other indicated weights (WBEGIN and WCOMP) present a greater delay (but still in the same minute than WABS). Moreover, they don't react to the very small weight variations and are only updated each minute. They are thus probably the "last" part of the filter mechanism that treats the raw weight in order to provide right rainfall intensities. The weight noise (WNOIS) is an interesting value. It is a result coming from the different algorithms that filter the raw data. It provides thus an indirect indication about the elements that perturbed the weight measurements, as for example the wind. Under the influence of wind over the bucket, dynamic pressure variations occur above the gauge orifice, causing thus weight fluctuations. The noise values could thus be used as indicator about the wind strength. Some specific tests about the noise are presented in the chapter 3.3.

Noticed “problems”

Sometimes a lap of 6 seconds between two measurements is indicated. It is normal because looking at the figure 13, it appears that the program send not exactly each 5 seconds (5.006 or 5.007) a query to get the data from the gauge. It can also sometimes occur that no information is sent for up to 20 seconds, but it is really rare.

2.5. Data provided with a temporal resolution of 1 minute

This resolution is available when the data transit through the data logger. Because it works as well as modem, the data logger is able to send the measurements to a server thanks to a GPRS (General Packet Radio Service) connection. It enables faster data transfer on the GSM (Global System for Mobile Communications) network.

If the strength of the GPRS signal is not sufficient (more information in chapter 2.6.1) the transmission of data will begin to encounter problem. But the logger will not loose these data, they will be sent when the signal will become stronger. The data logger stores anyway the data even if they are successfully sent. Only if during a long time the strength of the GPRS signal is not sufficient, some data will be lost, because the data logger begins to rewrite on its memory when it is full. The autonomy is about 1 month.

For this test phase, the measurements are sent to a server (<http://metnet.mps-system.sk:20002/eth/index.php>) belonging to the MPS System Company. All the measurements are available with a resolution of 1 minute. The data on the server are updated every ten minutes. This server is really user-friendly. All the data can be downloaded for example on an excel-sheet (csv file). It is as well possible to plot online the different values of interest for a selected period. Because the data are sent trough GPRS, less information is available as in the case with 5 second resolutions. Only the time of record, the 1 and 5 minute precipitation intensity, the absolute weight and the noise values are sent.

Noticed “problems”

When the data logger didn't have for a long time communication trough GPRS, it is not possible to have instantaneously the “new” data that are already sent to the data logger. After this time without communication, the logger will resent all the historical messages and it takes a few hours. But no data will be lost.

Moreover, sometimes, some part of the information sent by the data logger is missing or incomplete. It occurred only during a week-end, where on the total 10 minutes were missing and 26 minutes presented incomplete or empty information. The MPS Company said that this type of problem can occur but stays really rare.

Finally, it appeared as well during this test phase that the data logger seems to need time after an unplug of the gauge, before sending “correct” values. Indeed, the first precipitations indicated by the data logger present a curious behaviour. Detailed information about this problem is available in the chapter 3.1.1.2.

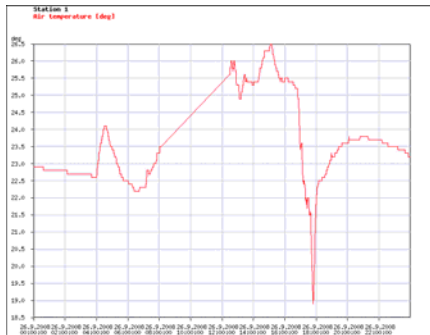


Figure 15 Problem with the graphs provided by the server

Concerning the server, the provided graphs just link the different measurement points with a line. So for example, if for a certain time no data were sent to the data logger, the graphs on the server will link the last “old” and the first “new” measurements. On the figure 15, it appears that wrong temperature values are indicated (on the straight line).

2.6 Presentation of the terminal v 1.9b

The terminal has several functions. Through different commands it is possible to either communicate directly with the rain gauge or with the data logger. On this way some different important parameters can be changed. To start the terminal, double click on terminal.exe in: \MPS-tools\Terminal.

2.6.1 Communication with the data logger

For that purpose, an **additional junction cable DB9 that links directly the logger to the computer is required**. This cable presents quite particular characteristics that not all DB9 cables have. All the pins must be wired. The cable with article number 671592 and type AA-317-06 from Distrelec works well¹. Moreover, **the green and yellow wires have to be connected to the data logger place**.

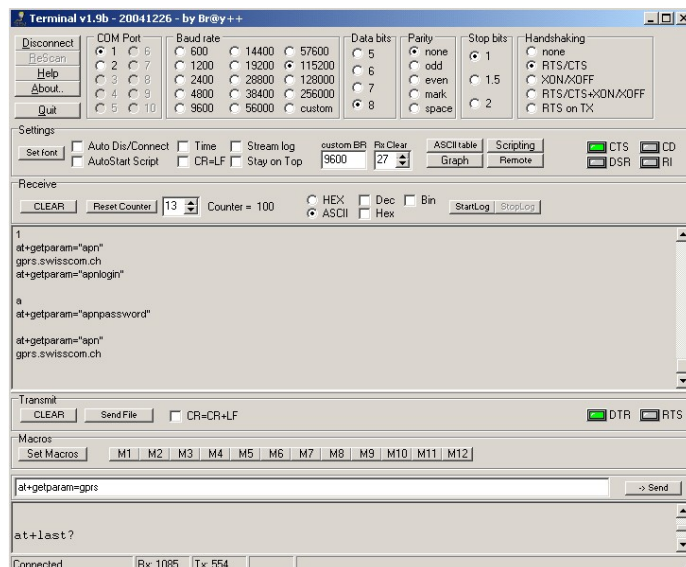


Figure 16 Terminal settings for dialoguing with the data logger

After the opening of the terminal, the following window will open. Check that this window presents the same settings than in the figure 16. Note that the DTR and the CTS buttons (below right and above right) have to be green. The CTS button becomes right when the button “connect” is pressed. (And thus the connect button changes in disconnect). It is not a problem if the CDM port is not the same. Just keep the one that is automatically selected.

¹ <https://www.distrelec.ch/ishopWebFront/catalog/product.do/para/node/is/DD-6787/and/highlightNode/is/671492/and/id/is/02/and/series/is/1.html>

Trough different commands that have to be entered in the grey field at the bottom of the window (and not in the white one!), it is possible to interact with the data logger. In the **operating mode**, some commands allow to dialogue with the data logger, mainly to ask about its state. The table 4 presents these commands.

Table 4 Some commands available in the operating mode.

Request	Command to type	Answer
Is it running?	at+wopen?	if it is running: +wopen:1 otherwise: +wopen:0
Is it connected to the GPRS?	at+cgatt?	+cgatt:1
What is the logger internal time?	at+cclk?	+cclk: "yy/mm/dd:hh:mm:ss"
What is the last measured data?	at+last (attention, without ?)	short or long response. More information in the original user guide.
Remove old messages until current time:	at+cutmail	OK
What is the strength of the GPRS signal	at+csq	A number between 0 and 32. Below 10, some problem for the data transmission can occur.

There is also a **maintenance mode** that is only accessible with a password. To switch to the operating to the maintenance mode the following command must be entered:

at+mtnc=password (The password is 1949)

The terminal will indicate that the maintenance mode is now activated trough the following answer: *maintenance logged mode*. When the maintenance is open, it is possible to change the time settings or to obtain some information about the preceding maintenances (See table 5).

Table 5 Some commands available in the maintenance mode.

Operation or request	Command to type	Remark
Change the time setting	at+time="yy/mm/dd, hh:mm:ss"	Attention, the logger restarts and all data records are deleted!
What is the number of restarts?	a+getparam="restart"	
What is the date and time of the last restart	at+getparam="stamp"	

Moreover, in the maintenance mode, it is possible to access to different parameters for consulting their current value and if needed to set new values. The procedure for consulting, changing and saving the parameter values is simple, as visible in the table 6. Don't forget to enter the "" before and after the parameter name.

Table 6 The procedure to check, set and save parameter values.

Operation	Command	Answer
Check current value of parameter	at+getparam="name"	<i>current value</i>
Set new parameter value	at+setparam="name", "new value"	OK
Save new parameter value	at+saveparam	

After the save, the logger will restart and the **maintenance mode will be closed**. Before saving it is worth to check that the modifications were well done checking again the current value of the changed parameters.

There are a lot of parameters that can be changed; it is as well possible to set different alarms. More information is available into the directory ...\\TRWS_manual\\MPS05CPU_logger. The files are however in Slovak.

Different parameters concerning the SIM card or the GPRS transmission are however presented in the table 7. To install the SIM card, it is just necessary to indicate its apn. For this test phase it was gprs.swisscom.ch. No values were entered for the apnlogin and the apnpassword.

Table 7 The parameters concerning the sim card.

name	values	meaning
gprs	0/1	1-SIM card with GPRS, 0-no GPRS
apn	string	SIM card APN
apnlogin	string	SIM card APN login
apnpassword	string	SIM card APN password

2.6.2 Communication with the gauge

The terminal allows as well “speaking” with the rain gauge directly from the computer. **Thus the green and yellow wires have to be connected to the PC place** and the information will transit by the converter and not be sent to the data logger. The **9 pin connection cable** that goes out of the converter must thus logically be **connected to the computer**.

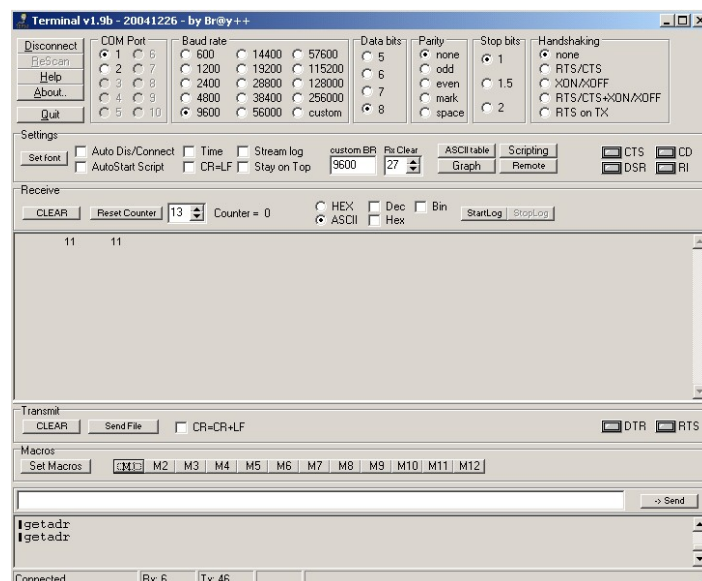


Figure 17 Terminal setting for dialoguing with the rain gauge

Once again, after opening the terminal, control that the opened window presents the same settings than in the figure 17. Note that for this case the DTR and the CTS buttons (below right and above right) have to be grey. Pay also attention, the Baud rate and Handshaking parameters are not the same as in the case where the terminal was used to interact with the data logger.

It is the same principle as when the computer was “speaking” with the data logger. There are also an operating and a maintenance mode. The different commands of the **operating mode** are available in the chapter 5.2 of the user’s guide ver. 3.1. Pay attention, they have to be surprisingly entered in the white field (and not in the grey field as in the case where the terminal were used to interact with the data logger).

In this user guide, the requests are not given in an “explicit” way. For example to ask the address of the gauge, it is written to type <ENQ>GETADR<CR>. With this command, the terminal understands that an enquiry <ENQ> that is getting the address is made. At the end it

is necessary to make understand the terminal that it is the end of the enquiry, using the Carriage Return command. <CR>.

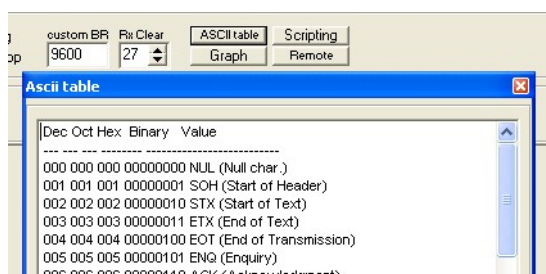


Figure 18 The Ascii table of the terminal.

But these commands have not to be entered on this way in the white window. It is first necessary to translate the commands that are between the <> with their ASCII code. The ASCII table can be consulted directly from the terminal, clicking on the corresponding button. Take only the first value (Dec) indicated on the left of the Ascii table (see figure 18).

Note that before the corresponding ASCII number, the # symbol has to be inserted. So, for <ENQ>GETADR<CR> it must be entered: #005getadr#013. The answer will be: 11. (It is the default address). Note as well that it is not possible to copy and paste the codes, the terminal doesn't recognize the command, each letter has to be entered. However, it is very easily to create macros that avoid always taping the codes, thanks to the Set Macros button.

A command of the operating mode in the user guide is not very clear. It is the one concerning the time synchronization. It is written that, when the TRwS is used with the datalogger, it is recommended to synchronise every minute 3 seconds before sending request for data. But, in fact this synchronisation is done automatically, so that nothing special has to be done.

As for dialoguing with the data logger, there is a **service mode**. The access doesn't require a password, it is just necessary to enter the following request:

OPEN<ADR>WS<CR> (it corresponds to: OPEN11WS#013).

To see the list of all the different possible commands in the service mode, enter the letter H. On this way, it is for example possible to change the heating temperature threshold temperature. Note that in the service mode, if any other commands than one expected by the terminal is entered, the service mode will quit and return to the operating mode.

The most important commands and the related answers are well presented in the user's guide chapter 5.3 and will be thus not developed here. Just a precision will be made concerning the way to change the rain gauge's address. There are indeed two different possibilities indicated in the user guide, but it is rather recommended to use the one of the service mode described on the point 5.3.8. Pay attention that the address should be a 2 hexadecimal chars, but in fact the terminal accepts all the value that are entered. During this test phase a wrong manipulation was made: instead entering 2 hexadecimal chars, the address 9<enter> was introduced. Because such an address can for example not be read by the usm program, it is absolutely necessary to change it. For this purpose, it was first necessary to enter in the service mode thanks to the command OPEN9#013WS#013 and after change as normally the address.

3. First tests

This part presents further experiments that were conducted with the different sensors available on the rain gauge. These tests will provide a better general understanding of the working style of the gauge and will also allow making some statements about the sensors accuracy. Thus, the intensity and temperature values provided by the gauge will be analyzed. Moreover, it will be also try to better understand and exploit the provided noise values, thanks to different analysis of the factors that engender noise.

3.1 Tests about rainfall intensity

With weighing rain gauges the intensity is directly derived from the continuous weight measurements. Thus, in order to better understand how works the gauge, the indicated intensity and the one calculated from the weight variations will be compared for the both available temporal resolutions. This comparison will as well allow assessing if some features of the data processing could lead to small rainfall deformations. Finally, this comparison also allowed demonstrating that the gauge was, as indicated by the manufacturer, able to eliminate unreal jump weights.

It is difficult to assess properly the intensity accuracy of the delivered rain gauge because reference values are missing. It was thus impossible to assess precisely the performance of the gauge regarding at the “counting” and “catching” errors. Therefore, the results of experiments conducted by the World Meteorology Organisation (WMO) will be in a second part briefly presented. They compared the performance of different rain gauges, including the TRwS, in laboratory and field conditions.

3.1.1 Calculation of the intensity

3.1.1.1 Data with 5 seconds resolution

The calculated intensity simply results from the difference of the absolute weights taken with an interval of 1 minute. Because of the 200cm² orifice, 20 g of water falling during 1 minute corresponds to an intensity of 1 [mm/min], under the assumption that the water density always amounts to 1000 kg/m³. The indicated intensity is the value provided by the rain gauge (see table 8).

Table 8 Calculation of the intensity.

Time	indicated Intensity [mm/min]	WABS [g]	calculated Intensity [mm/min]
08:13:46	0.606	1110.17	
08:13:51	-	1110.17	
08:13:56	-	1110.17	
08:14:01	-	1110.17	
...	...	...	
08:14:31	-	1116.678	
08:14:36	-	1116.678	
08:14:41	-	1116.678	
08:14:46	0.621	1122.588	0.6209

For a small rainfall event, these two intensities were compared. At the first sight, the results are quite identical (see figure 19).

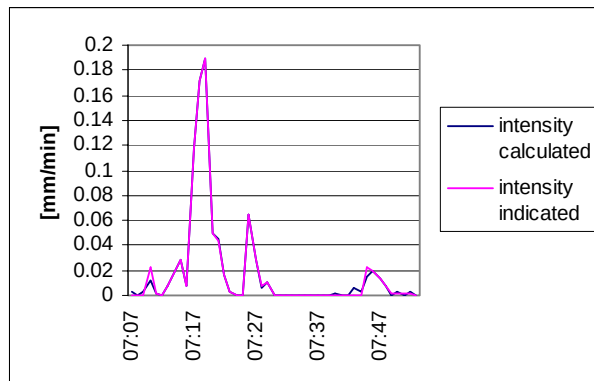


Figure 19 Comparison between indicated and calculated intensity for a light rainfall event.

Table 9 Zoom on the end of this rainfall.

time	Intensity [mm/min]	
	calculated	indicated
07:42	0.00015	0
07:43	0.0055	0
07:44	0.00265	0
07:45	0.0148	0.023
07:46	0.0201	0.02
07:47	0.0135	0.014
07:48	0.0077	0.007
07:49	0.0005	0.001
07:50	0.00255	0.002
07:51	0.0002	0.001
07:52	0.0026	0.002
07:53	0	0

Some discrepancies occur however at the beginning of the rainfall. Thanks to other similar analysis, it appeared that the rain gauge “needs” an intensity bigger than 0.01 [mm/min] in order to detect rainfall. This feature appears very clearly in this little rainfall event at for example 07:42 (see table 9). The intensity derived from weight differences indicates that it is raining. However, the gauge indicates the beginning of rainfall only at 07:45, when an intensity greater than 0.01 [mm/min] occurs. The first value indicated by the gauge is quite higher than the indicated one. It is a logical consequence, because all the precipitation that occurred before that the intensity threshold was reached are however taken in account. Thus for this example, the sum of the calculated intensity between 07:42 and 07:45 equals the indicated intensity of 07:45.

Once this threshold is reached, the gauge can then simulate lower intensities with a resolution of 0.001 [mm/min]. The residuals smaller than 0.001 [mm/min] are stored by the gauge and added to the next minute. It explains thus the small discrepancies observed in table 9 between the two intensities.

This characteristic leads to a small deformation of the rainfall feature, mainly at the beginning of light rainfalls. However, looking at the involved small concerned intensities, it is not a major problem. Moreover, the total amount of rainfall stays the same for both intensity values.

In order to have a full comprehension of the different rainfall deformations that could be made by the gauge, it is also necessary to look at the raw weight measurements. A more detailed analysis of the data allowed remarking that apparently the filter mechanism implemented to treat the raw data doesn't lead to additional rainfall deformations. Indeed, for all the cases observed, it appeared that the treated weight values (WABS) always were able to reproduce without significant deformation the behaviour of the raw weight values (WRAW). It is supposed that the characteristics of the real intensity are well caught by the behaviour of the raw weight. Even for the biggest observed rainfall peak of 1.2 [mm/min] that occurred moreover very quickly, the filtered weights were able to reproduce without any deformations this peaky pattern (see figure 20).

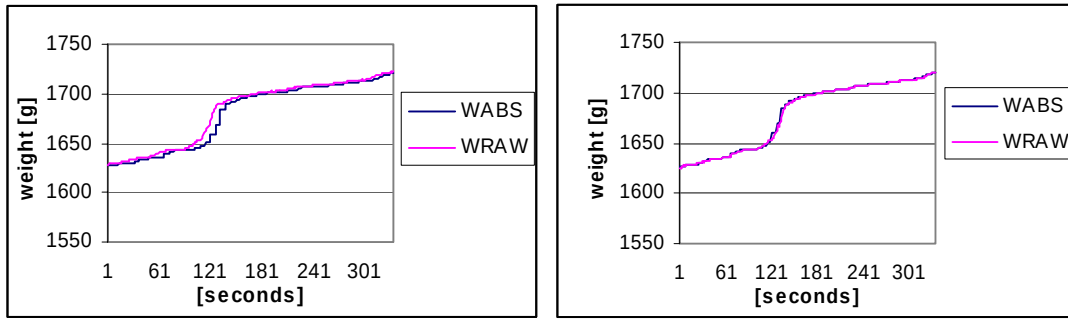


Figure 20 Left: Raw weight and treated weight in real time. Right: Removing the delay of 1 minute affecting the WABS values, it appears that the rainfall patterns are very well reproduced.

3.1.1.2 Data with 1 minute resolution

The same comparison was made for the case with one minute resolution data. For numerous rainfall events the indicated and calculated intensities were quite different, as for example for the one represented in the figure 21. The general feature of the rainfall is well caught, but looking at the individual intensities, quite high differences occur (see table 10).

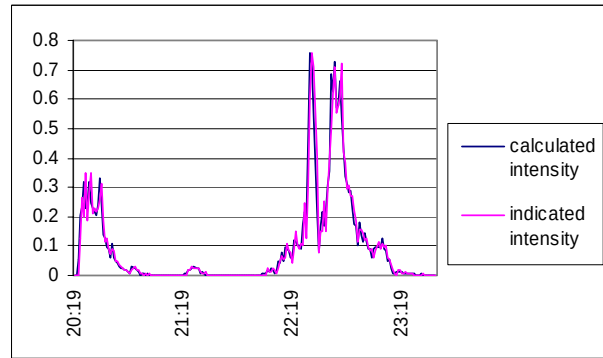


Figure 21 Discrepancies between indicated and calculated intensities.

Table 10 Discrepancies between caluculated and indicated rainfall intensity.

Time	indicated Intensity [mm/min]	calculated Intensity [mm/min]	WABS [g]	Noise [g]
20:19	0		1049.28	0.037
20:20	0	0.002	1049.32	0.392
20:21	0	0.057	1050.46	1.638
20:22	0.128	0.2055	1054.57	3.038
20:23	0.266	0.235	1059.27	2.6
20:24	0.196	0.3185	1065.64	2.681
20:25	0.348	0.2315	1070.27	2.184
20:26	0.188	0.2415	1075.1	3
20:27	0.28	0.3215	1081.53	2.946

After looking carefully at the whole set of data, it appeared that these discrepancies concerned the first rainfalls recorded by the data logger, after each time that the gauge was disconnected. Otherwise, it appears that the gauge works in the same manner than in the 5 seconds resolution case. Because a lot of manipulations were done during this test phase and that each week end the gauge should be disconnect and kept inside, a great proportion of the recorded data suffers from these discrepancies.

It is difficult to say if this problem only concerns the intensity value. Some clues tend to indicate however that the other measurements are not affected. First, the time indication stays always correct. Moreover, the noise and the absolute weight values seem not to be concerned

by this problem. Indeed, looking at the table 10, it appears that the “higher” noise value at 20:20 attests that it was already raining, as indicated by the difference of the absolute weights.

The laps of time as well as the amount or the characteristic of precipitation needed to again obtain “good” results is not clear. On the figure 21, three “distinct” rainfall events presenting sometimes high intensities were not sufficient. On the contrary, as visible on the figure 22 and the table 11, after a light precipitation during about 2 hours the data logger was able to “self recalibrate”

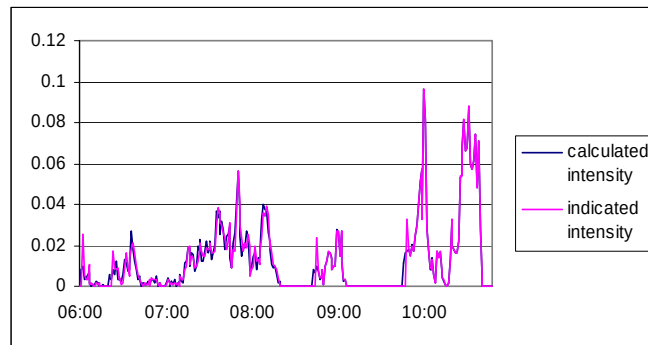


Figure 22 „self recalibration“ of the data logger.

Table 11 Zoom on different time of the rainfall.

time	indicated Intensity [mm/min]	calculated Intensity [mm/min]	WABS [g]	Noise [g]
06:00	0	-	5635.1	0.075
06:01	0	0.008	5635.26	0.142
06:02	0.025	0.01	5635.46	0.084
06:03	0.006	0.003	5635.52	0.057
06:04	0.003	0.004	5635.6	0.054
06:05	0.003	0.0055	5635.71	0.116
...	...	...	...	...
08:43	0	-	5667.35	0.069
08:44	0	0.0065	5667.48	0.108
08:45	0.024	0.0095	5667.67	0.07
08:46	0.007	0.007	5667.81	0.071
08:47	0.004	0.0035	5667.88	0.099
08:48	0.005	0.005	5667.98	0.072
08:49	0.008	0.0085	5668.15	0.029

As already mentioned, for the “good” part of transmitted data, it appeared that the indicated intensity features were comparable to the one obtained in the 5 seconds resolution case. Indeed, for this example, the indicated intensity from 08:43 corresponds to the calculated one. The same little discrepancies as the 5 seconds resolution case concerning the beginning of the storm are also well visible; the gauge needs again a threshold value of to begin recording the rain.

Finally, even if the data logger needs some time to “calibrate” itself after a restart, looking at the general features of the indicated precipitation, it appears that there are quite comparable with the one provided by the variation of weight. Moreover, the total amount of precipitation is the same in the both cases. So it seems not to be a major problem, all the more that it is possible to find the correct intensity making the calculations from the weight differences, that are assumed not affected by the data logger “warming phase”.

In closing, there are thus no differences in data processing between the two available resolutions, as indicated by the manufacturer. The both are computed in the rain gauge. Moreover, considering all the data up to now, it appears that the gauge is always able to provide the intensity with a constant delay of 1 minute. Thus, the filter software seems to be robust and able to filter the noise even during heavy rainfall or high wind periods.

3.1.1.3 Elimination of unreal step of weight

The comparison between the indicated and the calculated intensity allowed as well demonstrating that the gauge was able to eliminate unreal step of weights.

As visible on the figure 23, a jump in the absolute weight occurred during a light rainfall at 13:21. The rain gauge was however able to eliminate this improbable variation and simulated thus only an intensity of about 0.04 [mm/min] whereas the indicated one should provide more than 5 [mm/min].

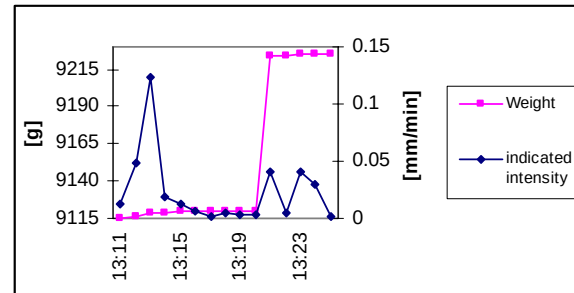


Figure 23 The jump in the weight is not reflected by the indicated intensity.

This elimination is very probably possible thanks to the different weights measurements WBEGIN and WCOMP presented in the chapter 2.4. They should probably not present this jump of about 100 [g]. These other weights are probably also the same that are able to store the non simulated rainfall below 0.01 [mm/min] before that the gauge already recognizes rain. Because these additional weights are also corrected according to the evaporation (indicated by the variation of WABS), the rain gauge is also able to simulate correctly the rain falling after evaporation period.

Unfortunately, it is difficult to completely understand the role of these other weights, because they are only available with 5 seconds data resolution, and in the conducted tests with this lower resolution no similar case occurred. But it is probable that the intensity is directly derived from these other weight differences that surely represent a kind of ameliorated weight measurement.

It is indeed comprehensible that the manufacturer decided to not provide these additional weight values with the 1 minute resolution data. If as above assumed, the intensity is directly derived from the variation of these other weights, they would give the same information than the intensity. Moreover, because of all the included filter mechanism in these measurements, they maybe could sometimes not correctly represent the present amount of water in the gauge and thus could make problem for example for the decision concerning the emptying time.

So, the choice to give the WABS and the intensity is interesting because it allows as well to detect where anomalies appeared, and thus to check if the corrections were justified.

3.1.2 Intensity accuracy

As already mentioned, the World Meteorology Organisation (WMO) organised very accurate tests in order to have an intercomparison of different rain gauges. In the first phase, different laboratory tests were conducted. For each rain gauge, precisely known constant water flow was generated and the relative error between the generated and the measured rainfall intensity was assessed. All the weighing gauges obtained very good results. (See figure 24, the devices in green) The MPS TRwS rain gauge presented a very small average relative error over the all

range of tested intensities, confirming thus the 0.1 % precipitation range intensity indicated by the manufacturer.

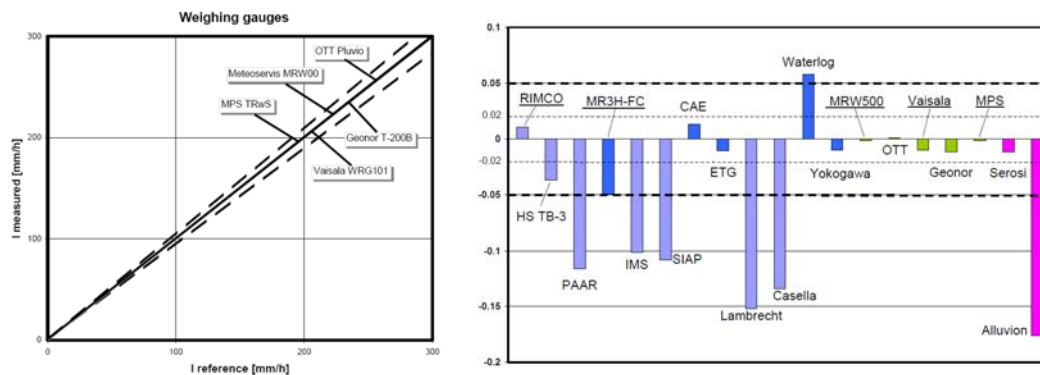


Figure 24 Left: comparison between generated and indicated intensity for all weighing rain gauges. Right: average relative error over all the different range of generated intensity. The weighing rain gauges are represented in green. Source : [2]

Just to confirm roughly these results, we conducted similar experiments. Different known weights were inserted in the rain gauge. The intensity indicated by the rain gauge was always correct.

Because the laboratory tests only provide indication about the “counting” and not about the “catching” errors of the gauges, the WMO did field tests to assess their performance under several climatic conditions. As reference 4 gauges selected on the base from the laboratory tests were chosen. These references were placed in a central pit in the middle of the field, while the other rain gauges were installed with equal distance as visible in the figure 25.



Figure 25 The field installation of all the tested rain gauges. Source : [3]

Unfortunately, even if these tests are already achieved, the final report and the results are not yet available. With the experiments that were conducted during our first test phase, it is not possible to roughly assess the performance of the gauge under different climatic conditions, because no references were available.

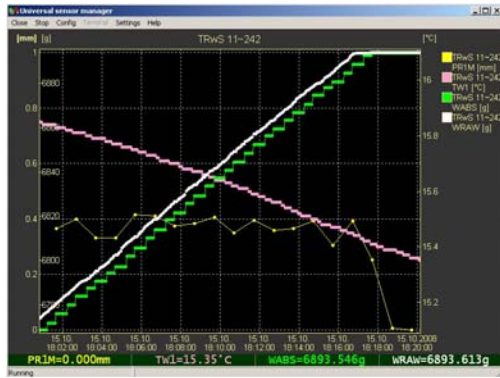


Figure 26 Wrong intensity simulation of about 0.003 [mm/min] after the end of a sprinkler test.

In the second phase of the tests, the rain gauge will be placed at Payerne and Zermatt, near to existing rain gauges from Meteoswiss. Thus, it will be possible to become a better idea about the performance of the gauge concerning the catching errors. During the first week, a snow fall was caught by the both devices in Payerne (see figure 27).

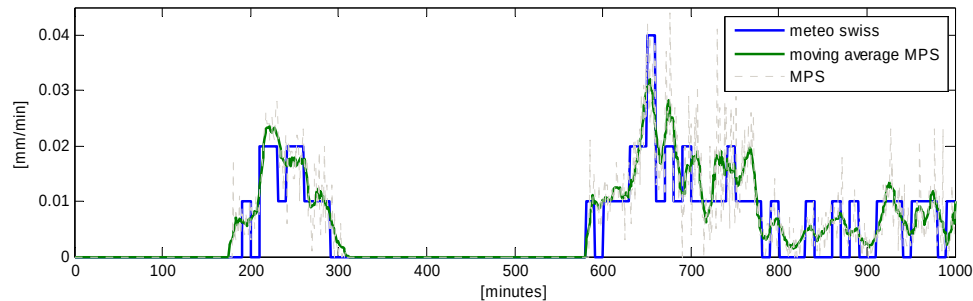


Figure 27 Comparison between the records of the both rain gauges. The measurements from the meteoswiss gauge were artificially extended to 1 minute resolution.

It seems that the MPS rain gauge is able to recognize before the beginning of the rain. It appears logical, because the meteoswiss device is a tipping bucket rain gauge that probably has a lower detection resolution. The tipping bucket has first to be filled. This delay didn't appear for the second snowfall, probably because the bucket was already almost full. The MPS indicated for this event an accumulated rainfall depth of 5.882 mm. The meteoswiss indicated only 5.1 mm. It represents thus a positive difference of about 15%. To interpret these discrepancies, more information is necessary about the rain gauge used by meteoswiss as well as the characteristics of the records provided by "Climap". Different factors could explain these discrepancies. As indicated in the introduction, the tipping bucket gauges can suffer from underestimation, but it is also possible to correct these errors. Different catching properties of the both devices could be also mentioned. Indeed, some discrepancies between the two gauges seem to be present between the 700th and the 800th minute of the observation. It would be interesting to look at the wind features that occurred at this time. Finally, maybe the resolution provided by Climap is not exactly the same than the rain gauge and could explain thus some differences.

However, generally the fit is good. The ameliorations provided by the MPS gauge concerning the assessment of the small scale rainfall patterns in time are huge.

3.2 Tests about temperature

The rain gauge provides two different temperature measurements. An external sensor indicates the air temperature. Another sensor situated on the strain bridge indicates the temperature “inside” the gauge. It is an important information needed by the filter mechanism of the rain gauge in order to delete the influence of the temperature on the weight measurements. Indeed, the resistance measured by the strain bridge presents a sensitivity to the temperature. This “internal” temperature serves as well to engage the heating ring, when the ambient temperature is below a threshold defined by the user. It could seem strange that the external temperature doesn’t serve as indicator for engaging the heating, but this external temperature is only an option that is not available on all the gauges.

3.2.1 Temperature accuracy

In this part the values provided by these two sensors are verified over a wide range of temperature thanks to different additional button temperature sensors. To simulate temperature ranges between 0 and 40 degree Celsius, a climate chamber was used. It was unfortunately impossible to get temperatures below 0 degree.

The comparison between two button sensors and the external sensor of the rain gauge provide excellent results (See figure 28). Just any discrepancies are visible (decrease after 40 degree and increase after 0 degree) principally for the second sensor. During this time, the climate chamber was set off and so no more ventilation occurs. Because the second sensor was not exactly at the same place than the two others, it is probable that the temperatures were already different.

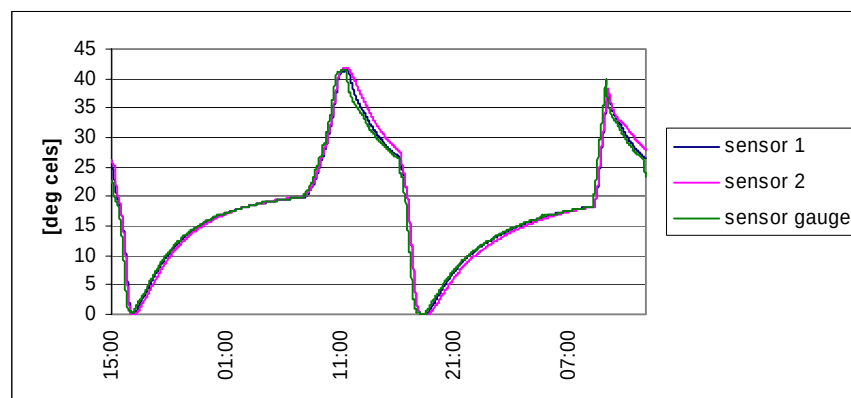


Figure 28 Comparison between two button sensors and the external air sensor of the gauge.

Further tests were conducted in “more natural” conditions. These tests were conducted because this external sensor is not ventilated. It is thus possible that, in case of low natural wind, the reflected shortwave radiation creates some deviations in measurements. To assessing this effect, a button sensor was installed at a shaded place that was protected from the incoming and reflected shortwave radiations. Just one comparative sensor was used, because with the first experiment it appeared that the both button sensors provide the same temperatures. On the contrary, the external temperature sensor of the gauge is exposed to these radiations. It appeared that the radiation play an important role in the measurements of temperature. It leaded to an increase of some degrees when the sun is present. There were also

more temperature variations, according to the instantaneous characteristics of the sun light cloud effects...). For the next experiments, a protection housing of the external sensor temperature was built. Some holes should allow the air to circulate around the sensor. It will logically not provide ventilated temperatures, but at least the effect of the sun will be reduced. To assess the improvement carried by this protection, comparisons will be available when the gauge will be installed nearby existing meteo swiss stations where also ventilated temperature measurements are available.

During the same experiment, another button sensor was used to check the accuracy of the “internal” rain gauge sensor. The results of the comparison indicate that there is a constant difference between the two measurements. Because it was not possible to place the button sensor at the same place than the one from the gauge, this test was redone inside. On this way, without the bucket and the housing, it was possible to place the button sensor exactly at the same place. It provided however the same results. The temperature sensor of the strain bridge constantly underestimates the temperature with a bias of about 0.6 – 0.7 degree (see figure 29)

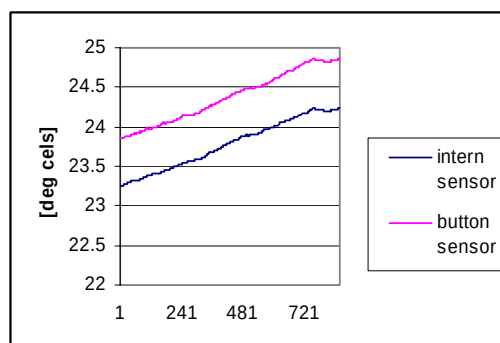


Figure 29 Bias affecting the intern sensor.

Generally, this error should not be problematic in the sense that other experiments seems to indicate that the bias stays constant over the different temperature ranges. On this way, it should not lead to non optimal corrections made by the filter mechanism that accounts for temperature weight variations. Indeed, as demonstrated in the chapter 235, the temperature – weight variation, seems to stay constant among wide temperature ranges.

With this constant error, the real threshold for engaging the heating ring amounts to 4.7 instead of 4 degrees. Regarding at the energy consumption of the heating mechanism, it could be worth to decrease this threshold. In this experiment it was difficult to assess securely if the heating ring worked properly. The ring stayed cold but the snow was not able to stay on this black part. On the contrary, on the white housing, the snow accumulated a little bit.

3.2.2 Temperature influence on the weight

As already mentioned, the temperature changes the resistance measured by the strain gauge and affect thus the weight measurements. It is logical, because the material of strain gauge presents a thermal expansion. For more information concerning the effect of temperature on the strain measurement accuracy, an interesting explanation can be found at the following address: <http://zone.ni.com/devzone/cda/tut/p/id/3432#toc0>.

The goal of this section is first to assess how strong is this dependence and secondly to check that the filter algorithms developed by MPS are always able to eliminate this dependence so that the gauge doesn't simulate “wrong” rainfall.

First, some experiments were conducted inside the office with some objects inside the gauge instead of water in order to remove the effect of the evaporation on the weight. All these experiments indicated that there is a strong negative correlation between the temperature and the weight (See figure 30). But the correlation only said how well the temperature – weight relation follows a linear relation. In this case it appears that the influence of the temperature on the weight is rather weak. (About -0.124 g/deg cels)

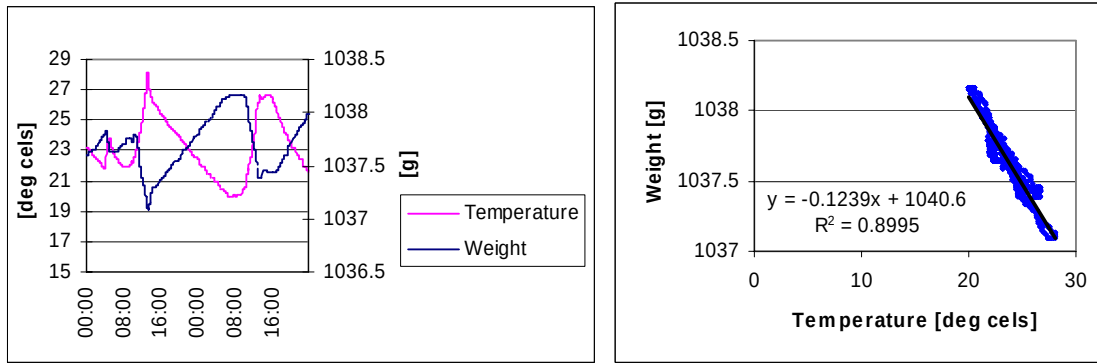


Figure 30 Temperature – weight relation

To test this dependence under all possible operative condition, the same experiment was conducted with other ranges of weights and wider temperature fluctuations. For this purpose, the rain gauge was differently lasted during the different temperature runs executed in the climate chamber (see figure 31).

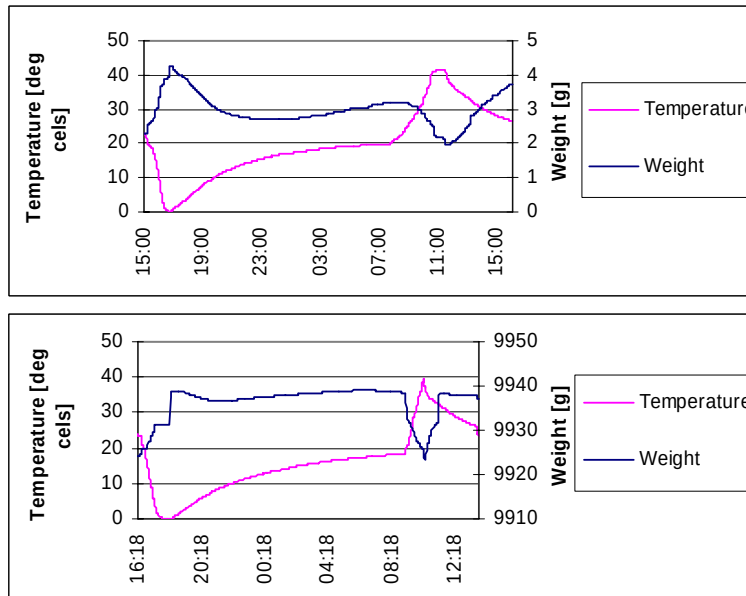


Figure 31 Temperature – weight dependence with two different initial weights.

It appears that this dependence presents sometimes quite strange behaviour. In these two temperature runs, the before noticed negative correlation was sometimes not any more observed. This “anomaly” appears better looking at the figure 32.

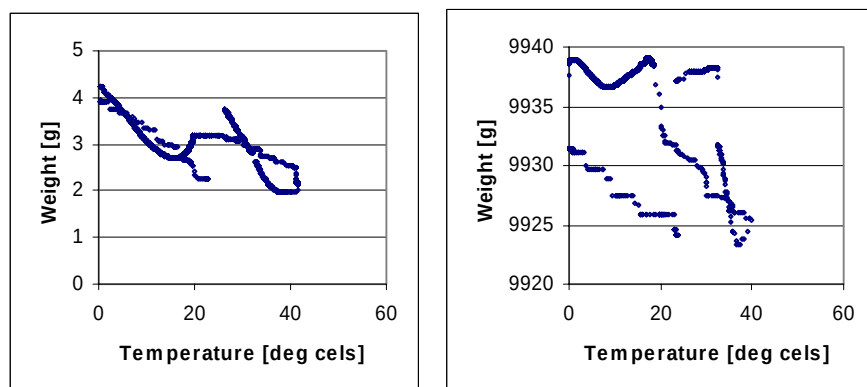


Figure 32 Temperature – weight relation for the both initial weights.

Selecting only the data of this test presents a regular behaviour, it appears that the initial weight plays an important role in regard to this temperature-weight relation. The bigger the initial weight, the stronger the relation (See figure 33).

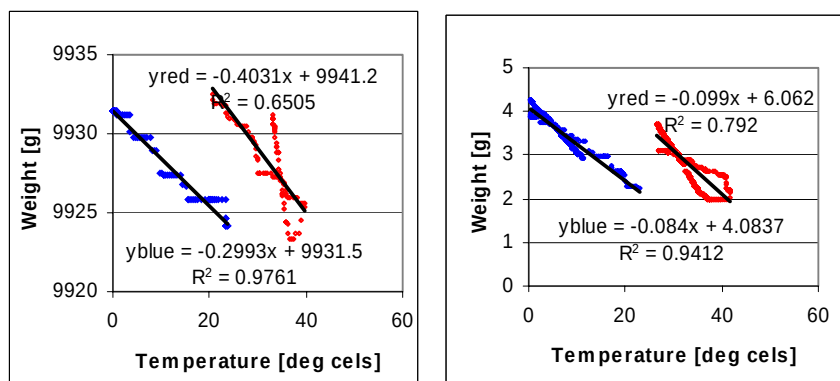


Figure 33 Relation temperature – weight for selected data of the both experiments.

This observation was confirmed with experiments involving other range of weights (see table 12). During these other experiments, also strange behaviour in the weight – temperature was as well sometimes observed.

Table 12 Effect on the initial weight on the temperature - weight dependence.

Initial weight	Relation temperature weight
0 kg (Empty without bucket)	-0.0884 (-0.099) [g/deg cels]
1 kg (Empty with bucket)	-0.1239 [g/deg cels]
3.8 kg	-0.193
10 kilos	-0.2993 (-0.4031) [g/deg cels]

This temperature influence is also well observed with „natural“ observations, when the gauge is placed outside. The following example illustrates quite well this effect and provides a more concrete vision of this influence (see figure 34).



Figure 34 Temperature – weight influence in natural conditions

To be sure that this dependence will not create wrong measurements under all possible operative conditions, the 1 minute precipitation data provided by the gauge during the different temperature run tests were analysed.

For the empty case, it appears clearly that the filter mechanism was able to avoid simulating wrong rainfall measurements, even if the intensity calculated from the weight variations was sometimes greater than 0.01 mm (see figure 35). These results are very encouraging, because, normally, intensities bigger than 0.01 mm/minute should be sufficient in order that the rain gauge begins to record the “rainfall”. Thus, it is a demonstration that the filter mechanism was in this case able to avoid simulation of wrong rainfall.

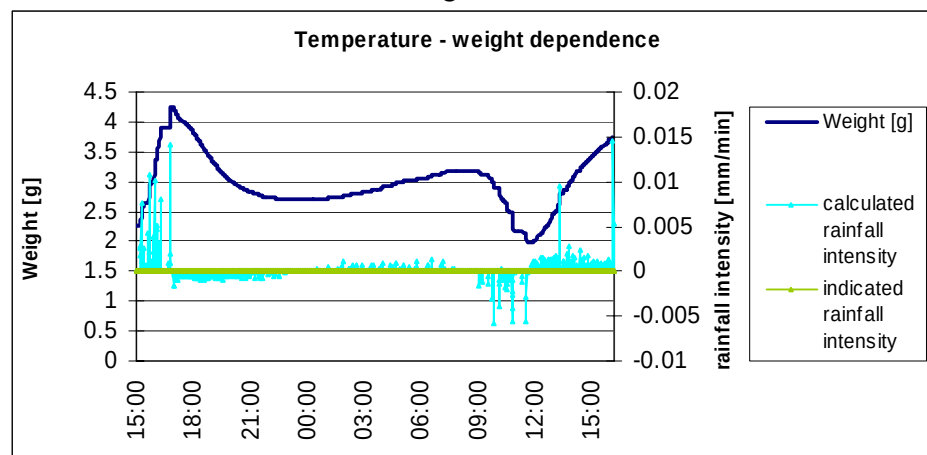


Figure 35 Comparison between calculated and indicated intensity during the different temperature runs.

For the case with about 10 kg in the gauge, the filter mechanism was also able to avoid simulating intensities greater than 0.01 mm/min. However, for two cases, the rain gauge simulated “wrong” rainfall of about 0.3 mm/min. These intensities are high and logically linked with some jumps of the weight (See figure 36).

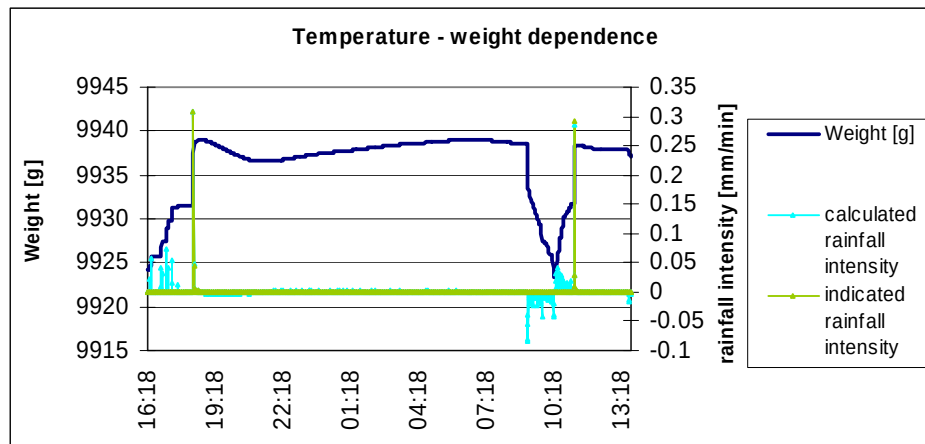


Figure 36 Comparison between calculated and indicated intensity during the different temperature runs.

With a better analyze of these jumps, it appears that they occur when the heating mechanism of the climate chamber was set off. Thus, the noise was dramatically reduced because of the stop of the ventilation device (See figure 37). This abrupt change of the environment probably disrupted the filter mechanism and led to wrong simulations. So, because these noise features are totally artificial and would not occur in the nature, it is probably not a big problem that the rain gauge simulated wrong rainfall in this case.

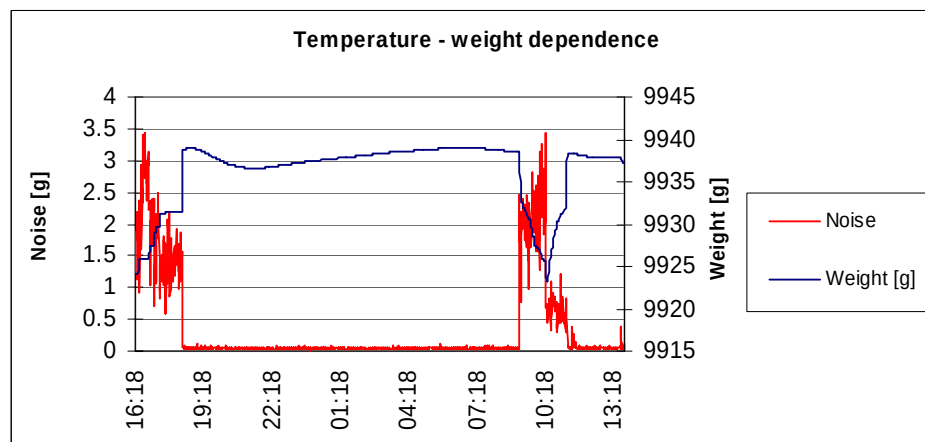


Figure 37 Noise values during the temperature run.

Finally, after these different experiments, it seems that under all operative conditions, the filter mechanism of the gauge are able to take into account this complex weight-temperature variation and avoid thus the simulation of wrong rainfall.

This temperature dependence seems thus to not represent a problem for questions related to the simulation of rainfall intensity. But, this dependence plays a role for the calculation of short term evaporation. There is also a negative correlation between the rate of weight variation and the temperature variation. When the temperature increases, as already observed, the weight decreases. It encourages higher evaporation rates. On the contrary, very low or sometimes even positive variation rates are observed when the temperature decreases (See figure 38).

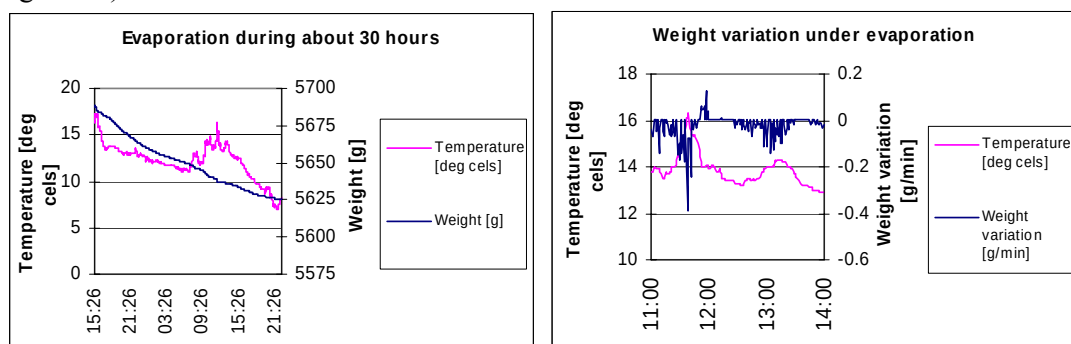


Figure 38 Left: evaporation during about 30 hours. Right: weight variation during a period with changing temperatures.

The sun could in part explain this behaviour. With sun more energy is available, enhancing thus higher temperatures. The incoming radiation has probably also a non negligible influence on the evaporation rate. So when the sun disappears, the temperature goes down as well as the evaporation rate. But this sun effect can't explain the positive weight variation that occurs during a strong phase of temperature decrease.

So, looking at these results, it seems more carefully to derivate the evaporation rates at higher aggregation scale, or not only during a heavy increasing or decreasing temperature phase. Looking at the evaporation over the whole period, these variations become negligible.

3.3. Tests about noise

The strain bridge provides weight measurements 24 times pro second. In order to provide stabilised weight values, different complicated algorithms are implemented to filter the weight measurements. These algorithms also provide weight noise values in gram. These values are thus an indirect indicator of the different elements that troubled the weight measurement. The characteristic of these values will be first briefly presented in the both case of 5 seconds and 1 minute resolution. In the second part of this chapter, different tests will be conducted to find a relation between the measured wind and the recorded weight noise, in both cases with and without rainfall. On this way, only the weight noise values could be able to provide a rough indication about the wind conditions

3.3.1 Features of the noise

As already mentioned in the tests for the rainfall intensity, the data are processed in the same way for the both resolution cases. However, looking at the noise features with a resolution of 5 seconds will allow to better understand how these values are calculated.

Table 13 5 seconds resolution noise

Time	Intensity [mm/min]	WABS [g]	WRAW [g]	NOISE [g]
16:54:41	0.217	1647.719	1652.259	3.975
16:54:46	-	1647.719	1655.398	3.975
16:54:51	-	1647.719	1655.259	3.975
16:54:56	-	1647.719	1656.934	3.975
16:55:01	-	1647.719	1660.025	3.975
16:55:06	-	1647.719	1660.464	3.975
16:55:11	-	1650.72	1662.947	7.41
16:55:16	-	1650.72	1664.016	7.41
16:55:21	-	1650.72	1666.907	7.41
16:55:26	-	1650.72	1666.847	7.41
16:55:31	-	1650.72	1668.865	7.41
16:55:36	-	1659.582	1672.232	11.024
16:55:41	0.593	1659.582	1672.232	11.024
16:55:46	-	1659.582	1675.258	11.024
16:55:51	-	1659.582	1680.252	11.024
16:55:56	-	1659.582	1682.716	11.024
16:56:01	-	1659.582	1683.724	11.024
16:56:06	-	1659.582	1685.791	11.024
16:56:11	-	1668.756	1687.319	15.287
16:56:16	-	1668.756	1688.092	15.287
16:56:21	-	1668.756	1688.854	15.287
16:56:26	-	1668.756	1689.102	15.287
16:56:31	-	1668.756	1689.943	15.287
16:56:36	-	1684.098	1689.489	4.849
16:56:41	1.226	1684.098	1689.489	4.849

Looking at the 5 seconds resolution noise data, it appears that the noise value stays constant for a period where WABS also stays constant. Moreover, it seems that the noise values describe the conditions that occurred 25 or 35 seconds just before that WABS is updated. (See the different colours in table 13 linking a jump in WABS with the noise values). Indeed, logically great differences between two consecutive WABS, signifying thus high intensities, are linked with higher noise values. But, as already mentioned, WABS presents a delay with the real time (WRAW). It oscillates between 25 or 35 seconds and 1 minute according to the time of the latest update. Thus, the indicated noise values present a delay between 0 and 25 or 35 seconds with the real time.

This delay in the noise is in fact quite logical and better comprehensible considering how works the gauge. It seems that the gauge analyses all the weight measurements during 25 or 35 seconds and, from the variations of these values, can provide a noise value. Logically this noise can only be indicated when the last measurement is taken in account, involving thus some delay. In this case it is 25 or 35 seconds, according to the number of values analysed for the noise computation.

Another feature not directly related with the noise feature is a little bit problematic. It appears that during a selected minute where the intensity is calculated, there are three different noise values, because there is a shift between the update of WABS and the time where the intensity is indicated. For example, for the intensity of 1.226 mm/min, the noise values of 11.024, 15.287 and 4.849 [g] are considered. Looking at all the different measurements made with 5 seconds resolution data, this shift occurred quite frequently.

This shift is problematic for the aggregation of the noise values with 1 minute resolution. Unfortunately, no information is available on how is aggregated the 1 minute noise resolution. It is thus possible that the gauge aggregates these three different noise values for the 1 minute resolution case. According to the previous mentioned characteristic of noise, it would thus introduce partly noise information that is not concerning the considered minute. It could on this way provide less accurate values for the 1 minute resolution case.

Looking at the noise values provided with a resolution of 1 minute, it appears very clearly that the noise comes one minute before the related intensity (see figure 39). Considering the delay of 1 minute that affects the intensity values, the noise values should thus be “real time” indications.

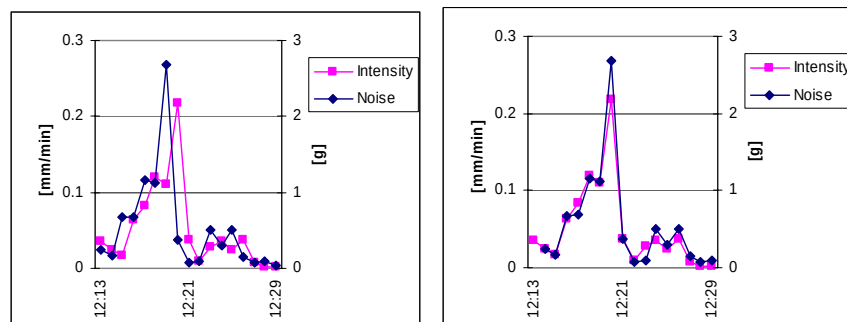


Figure 39 Right: Intensity and noise measurements. Left: the noise is retarded of 1 minute.

3.3.2 Wind noise relation

In order to find out this relation, it is first necessary to better understand which factors create noise and what is their relative contribution of the total recorded noise.

It is assumed that two factors, the wind characteristics and the rainfall intensity, are responsible for the major part of the recorded noise. Moreover, it is as well assumed that the total weight of water present in the bucket could also play a role on the noise response, for example through a more pronounced attenuation of the gauge vibrations with increasing weight. So, in order to isolate the effect of each factor, as well the effect of the rainfall intensity as the one of the wind characteristic will be assessed under different initial weight conditions.

However, before starting these experiments, it is first important to estimate the ground noise of the rain gauge.

3.3.2.1 Assessment of the ground noise

In order to become an idea about this ground noise, the gauge was kept inside during many week-ends, where it was assumed that no perturbations occurred. (No wind effect, no rainfall, no human disturbance...) Thus, the noise should mainly stem from the sensors or from the electronic components.

These experiments were also conducted with different initial weights (see figure 40).

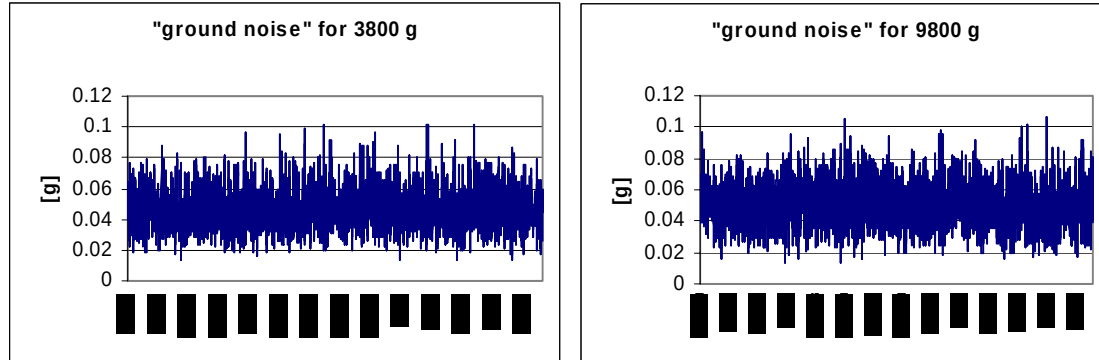


Figure 40 Left: ground noise for 3800 g. Right ground noise for 9800 g.

Looking at the table 14, it appears that the mean and the standard deviation of the ground noise increase a little bit when the weight as well increases. But these changes stay small and it is not worth to take this phenomenon into account for the continuation of these experiments. The distribution of these noise values diverges from a normal one for the lowest and the highest quantiles (See figure 41). Moreover, the weight doesn't seem to influence the distribution.

Table 14 Basic statistics of the ground noise for 2 different weights,

Initial weight [g]	3800	9800
Noise mean [g]	0.0468	0.0496
Standard deviation of the noise [g]	0.0136	0.0143
Minimum noise value [g]	0.013	0.013
Maximum noise value [g]	0.102	0.106

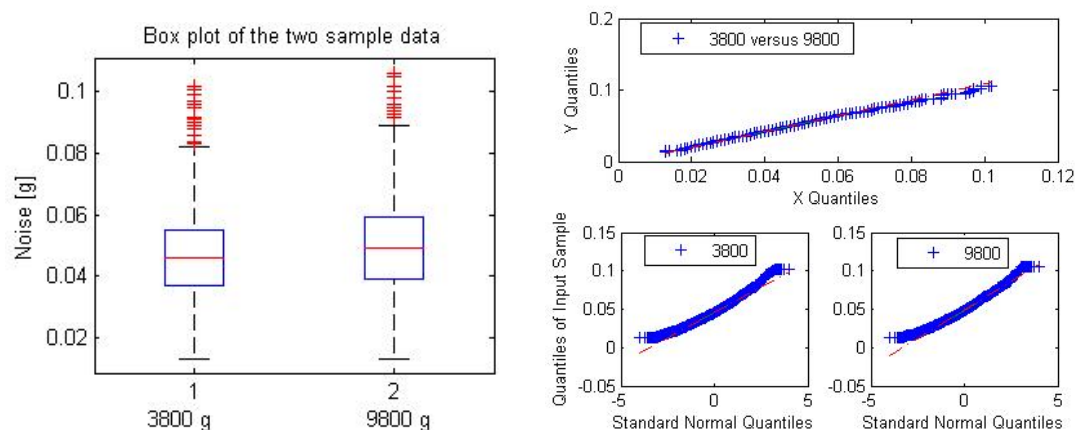


Figure 41 Left: Box plot. (median, lower and upper quartile values) The black line extending each end of the box show the extent of the rest of data. The red outliers are values that don't belong to this interval. Up right: QQplot of the two series. It represents more a less a line, signifying thus that the two series share the same distribution. Down right: QQplot of each series compared with a normal one.

Looking at the distribution of the data, high ground noise values that could be wrongly associated with extern perturbations occur quite rarely. Moreover, because the following tests in order to exploit the noise values are conducted with a resolution of 5 minutes, high ground noise values should be diluted, reducing thus the associated risk of wrong interpretations.

3.3.2.2 Wind induced noise

The wind can involve noise in the measurements mainly because of dynamic pressure variations over the orifice of the rain gauge. So it is not a trivial problem, because it could be imagined that the wind characteristics, such as intermittency or changes in direction and wind speeds could induce more noise than a regular middle wind velocity in regard to the caused dynamic pressure variations. Another effect from the wind could be the creation of vibrations of the rain gauge that could be reflected in the weight measurements.

To assess properly all these effects, sophisticated tests should be conducted, where the wind features could be precisely controlled. Maybe some interesting properties could be discovered, but it is probably complex relations. For example, it would be not surprising to obtain the same amount of noise for different wind conditions. Thus, in regard to the goal of roughly and simply assess the wind velocity thanks to the noise patterns, these tests would be exaggerated.

For this experiment, an anemometer was placed at the same height than the orifice of the rain gauge. The anemometer provided data about wind velocity and wind direction with a resolution of 5 minutes.

a) Assessment of the weight influence

It was initially planed to conduct different tests aiming at assessing the effect of the initial weight in the bucket. Unfortunately the anemometer was only for four days available, and because of quite cloudy conditions, the solar panel was not able to powering continuously the anemometer. Because of that just 2 days of data with empty bucket were usable. The experiment made with about 5 kilos weight in the bucket just provided 1 hour of data that are not usable.

However, thanks to other experiments made before that the availability of the anemometer, it seems that the total weight in the bucket plays a role concerning the noise. The water present in the gauge seems indeed to attenuate the weight variations and thus the noise created by the wind (see figure 42).

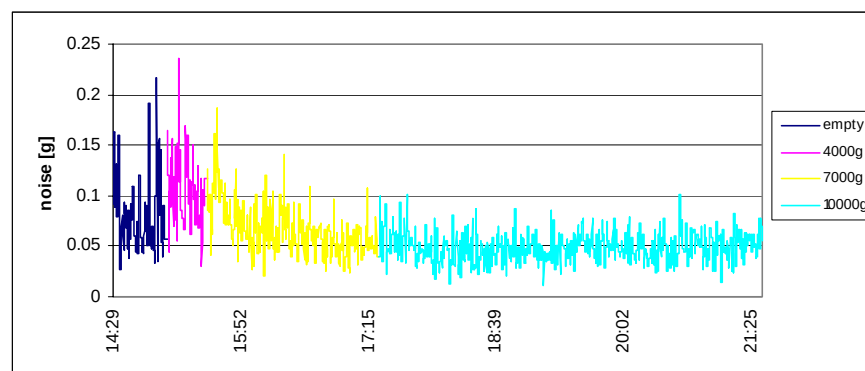


Figure 42 Noise values during a day where the initial way was regularly increased.

It is unfortunately impossible to prove and to quantify this effect, because the variations in the behavior of the noise could also be only explained by different wind conditions that occurred. It is however better to take precautions and consider that the experiments that will be now presented in order to find a relation between the noise and the wind speed are only valid for an empty rain gauge.

b) Analysis of the recorded noise and wind data

First, some preliminary tests on the noise and the wind measurements are made in order to better understand the different connexions between these two sets of data. The correlation between the noise velocity, the change in wind direction and in wind speed are thus assessed as well for the 5 minute noise mean and the variance of the 5 considered 1 minute noise values (see figure 43).

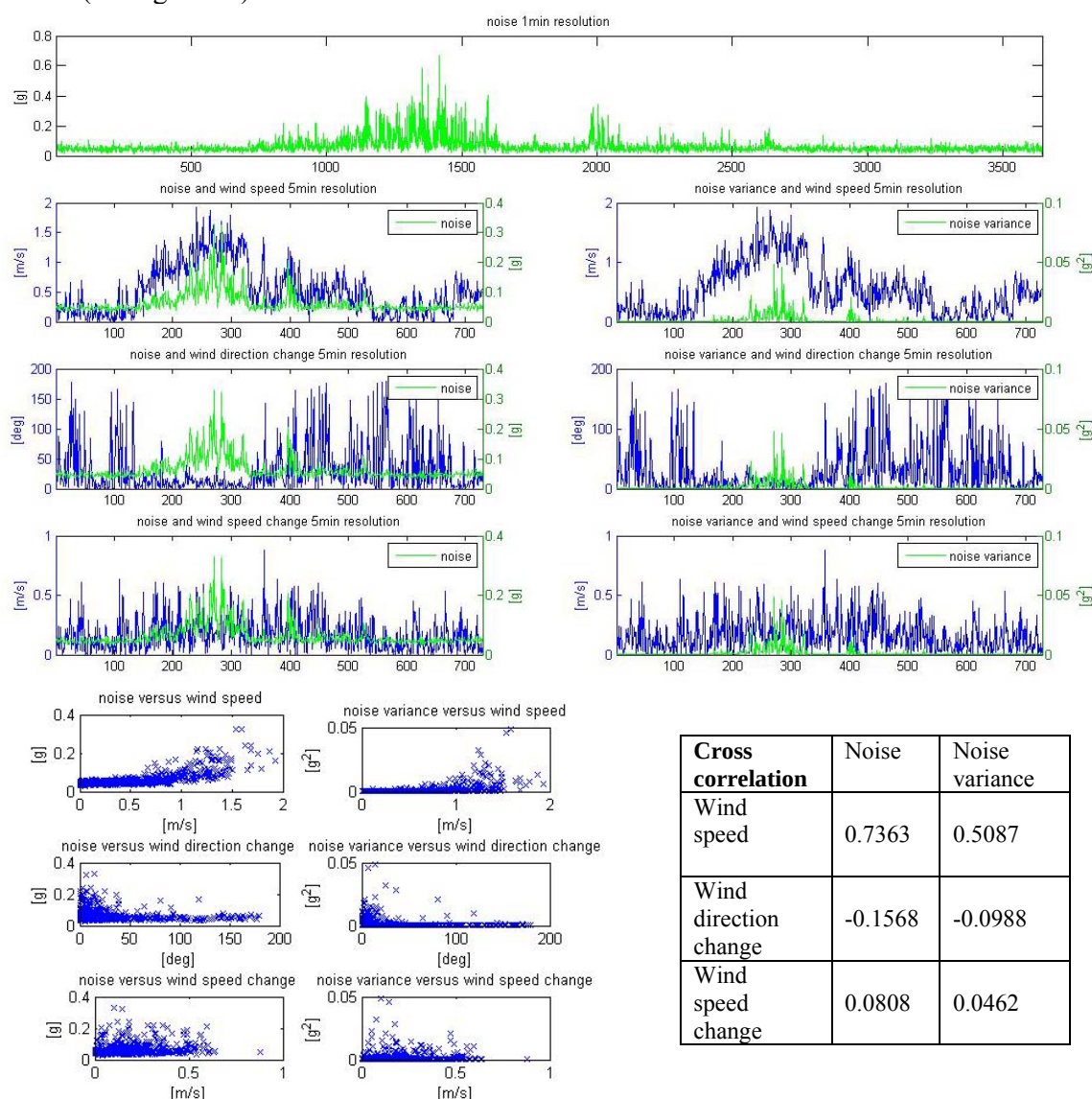


Figure 43 Above: the two different data sets. Below: cross correlations.

It appears that for the 5 minute resolution the wind speed changes are not significantly correlated with the noise mean or the noise variance. Concerning the wind direction changes, a weak negative correlation between the measurements is present. An explanation could be that during low wind conditions the direction of wind is not very well defined, leading thus to higher changes in direction. These great direction changes are thus linked with small values of noise, because of the very discrete feature of wind, leading so to rather negative correlations. On the contrary the wind speed presents a high positive correlation with the noise features. Generally, the noise mean presents a higher correlation with all the wind properties, indicating thus that it is a better indicator in order to assess the wind influence on the gauge.

These results are very good regarding at the purpose of assessing the wind speed from the noise values. The effect of the wind speed and wind direction changes will be interpreted indeed as negligible. If a significant correlation would be present between the wind direction and speed changes, it would be quite more difficult to assess the wind speed with the noise values. Indeed, it would introduce an uncertainty in the interpretation of the noise values, because it would be impossible to separate the effect of these different factors only thanks to the indicated noise values.

However, it doesn't necessarily signify that the in this case neglected factors don't have influence on the noise. Probably the 5 minute resolution is not sufficient in order to assess their effect and their influence could thus be diluted among the 7200 weight measurements that occurred in 5 minutes.

Thus, according to these preliminary tests, the 5 minute noises mean will be used in order to predict different wind speed ranges.

c) Prediction of the wind velocity from the 5 minute mean noise values

The goal of this part is to select threshold noise values that are able to class properly the observed wind in different classes.

For this set of data presenting low wind velocities, the wind will be classed in 4 different classes, as indicated in the figure 42.

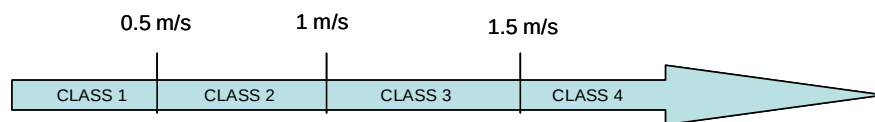


Figure 44 Separation in 4 classes of the observed wind.

A matlab program (see appendix B1) is responsible for selecting the noise threshold values that predict in the best way the wind velocity classes. The procedure is easy. Thanks to the wind measurements, the program knows the observed values. It can thus easily assess if a proposed noise value would represent a good threshold, regarding at different comparisons between the predicted data (from noise thresholds) and the observed true data.

So, for each class of wind, the program considers a lot of possible threshold noise values and just selects the one that maximises the specificity (proportion of positive case correctly predicted) and the sensitivity (proportion of negative case correctly predicted). These best predictors are also graphically visible thanks to the ROC plots provided by the program (see figure 43)

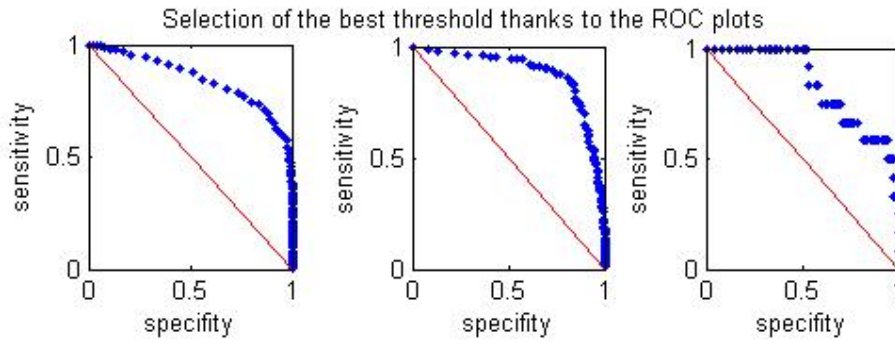


Figure 45 ROC plot. 3 different plots are obtained for the selection of each threshold noise value corresponding to the wind velocities of 0.5, 1 and 1.5 m/s

These plots also allow assessing about the validity of the general model chosen to predict the wind speed classes. It appears that the model is not perfect because the area below the blue points is smaller than 1. It is indeed logically, because here a very simple relation between noise and wind speed is assumed, whereas the noise values are quite complex and depend from a lot of other factors. But looking at the red right line, representing a hazard prediction, it appears that this procedure is however able to choose threshold values presenting good specificity and sensitivity patterns.

Table 15 Characteristics of the 3 different selected thresholds.

Wind velocity [m/s]	0.5	1	1.5
Corresponding noise threshold [g]	0.055528	0.078276	0.10748
Specificity [-]	0.87	0.84	0.95
Sensitivity [-]	0.69	0.83	0.58

Ranking all the mean noise values according to the above three obtained thresholds, it is now possible to rebuild the wind speed in classes (See figure 46).

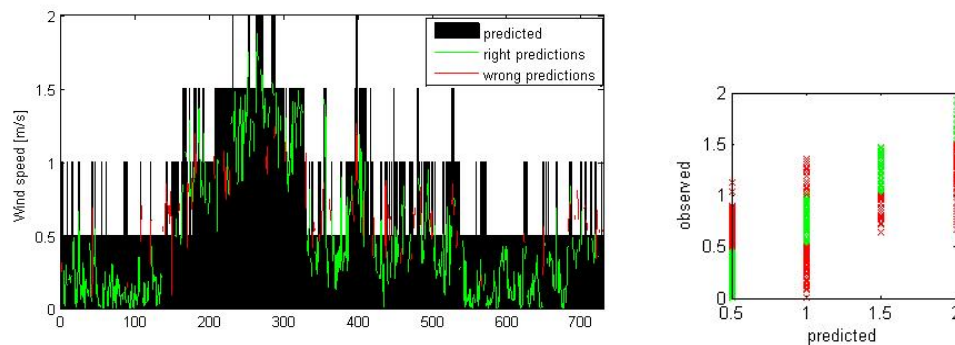


Figure 46 Comparison between the predicted and observed wind speed classes.

The results are quite good. The success rate, defined as the percentage of observations that are contained in the predicted wind speed range, amounts to 67.35 %

It is worth to progressively eliminate in the program the predicted and observed values that are above the best selected threshold. Otherwise, the computation of the sensitivity and the specificity is skewed and lead thus to the selection of non-optimal threshold values, even if looking at the so obtained threshold, better sensitivities and specificities can be obtained (see figure 47). In this case the classification would only present a success rate of 64.34%.

Wind velocity [m/s]	0.5	1	1.5
Corresponding noise threshold [g]	0.055528	0.065501	0.10839
Specificity [-]	0.88	0.89	0.93
Sensitivity [-]	0.69	0.93	1

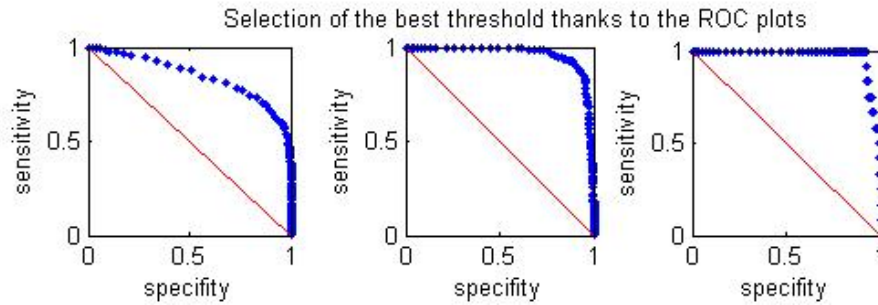


Figure 47 Characteristics of the 3 different selected thresholds (without elimination). Below: The related ROC plots

In order to test the robustness of the prediction, it is interesting to separate this data set in a calibration and a validation parts. It is indeed interesting to understand if these results are only good because they consider the all set of data and thus “know” all the reality.

d) Assessment of the robustness of the threshold selection

In a first attempt, the 1st third of data was selected as calibration period. The selected threshold values allow obtaining a success rate of 74.1 % (see figure 48).

Wind velocity [m/s]	0.5	1	1.5
Corresponding noise threshold [g]	0.055528	0.088439	0.19216
Specificity [-]	0.88	0.84	0.94
Sensitivity [-]	0.79	0.82	0.75

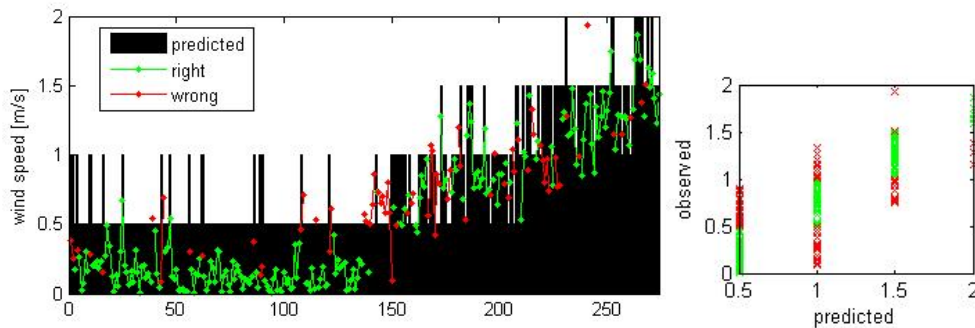


Figure 48 Above: chosen threshold value for the calibration period. Below: comparison between the so predicted and observed wind speed classes.

After that, the obtained threshold values were applied to the validation period, providing a success rate of 69% (see figure 49).

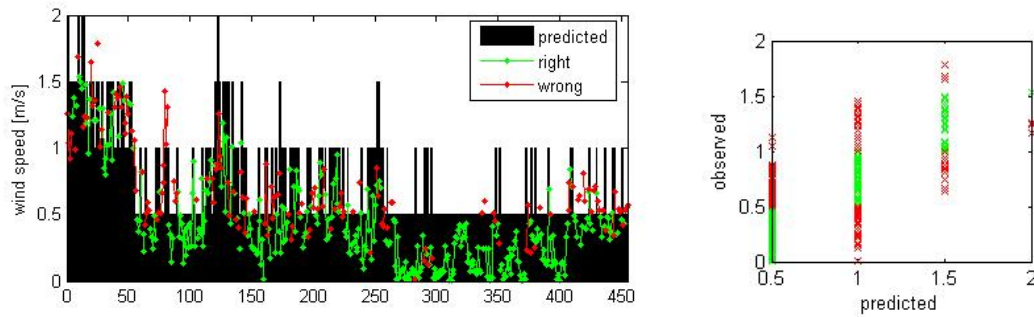


Figure 49 Validation period: comparison between the predicted and observed wind speed classes.

It provides on this case very good results that were even better than the one obtained considering the whole data set. In order to better understand why better threshold values are obtained, the correlation between the 5 minutes mean noise and the wind speed was analysed for this case (see figure 50). It amounts to 0.7775 and is thus more elevated than for the all set of data (0.7363). The correlation characterising the data set could thus play a role in the success rate of the selection.

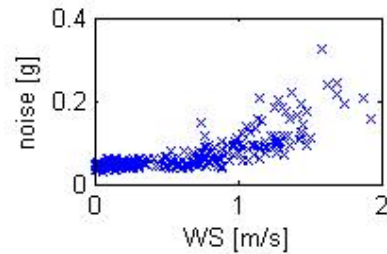


Figure 50 noise wind speed relation for the calibration period (first third of data)

To confirm the influence of the “quality” of the data set on the threshold selection, a calibration period presenting less clear dependence between noise and wind speed was selected (see figure 51). The correlation coefficient amounts to 0.6866. As expected, as well on the calibration as in the validation period, lower success rates are obtained: 64,21% for the calibration period and 69.82% for the validation period (see figure 52).

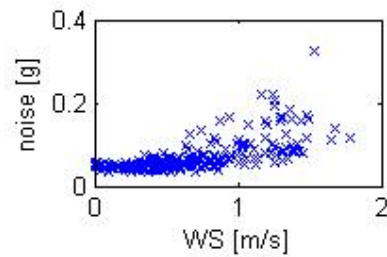


Figure 51 noise wind speed relation for another calibration period (second third of data)

Wind velocity [m/s]	0.5	1	1.5
Corresponding noise threshold [g]	0.057320	0.076615	0.107630
Specificity [-]	0.9	0.81	0.55
Sensitivity [-]	0.68	0.88	1

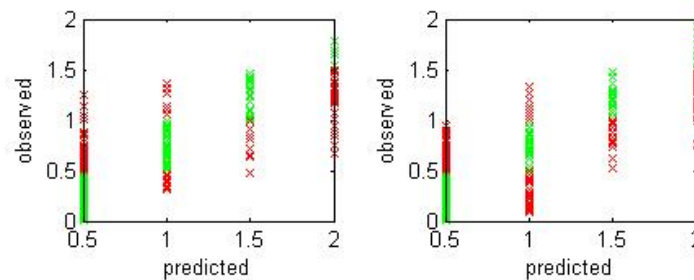


Figure 52 Above: selected threshold. Below left: comparison for the calibration period. Below right: comparison for the validation period

However, it appears that the differences between the success rates obtained with the different calibration periods are not so high. Moreover, even if the calibration is made on a data set presenting a smaller correlation between the noise and the wind speed, the selected threshold values are however able to provide good results for the validation period. So, it attenuates a little bit the influence of the data set quality on the success rate. It indicates thus that the selection algorithm is quite robust. Moreover, looking at the selected threshold values for the 3 different cases, there are not big differences, except for the one concerning the wind speed class greater than 1.5 m/s. After a better analyse of the data set, it appears that this difference is logical looking at the procedure that define the best threshold. Indeed, the same weight is given to the specificity and the sensitivity. Because the data set contains only a few wind observations that are bigger than 1.5 m/s, there are more chances to make wrong positive (bigger than 1.5 m/s) predictions than to make right positive predictions. Thus, logically the program selects quite conservative value of the upper threshold, in order to increase the number of right positive prediction. These low thresholds lead logically to sensitivity value near to 1 and lower specificity values. Only for the calibration period that concentrated a higher proportion of wind velocities greater than 1.5 m/s, the program selected a quite higher threshold value (see table 16)..

Table 16 Comparison of the obtained thresholds between the different calibration periods.

	Corresponding noise threshold [g]			Proportion of wind observation above 1.5 m/s
	0.5 m/s	1 m/s	1.5 m/s	
Whole data	0.055528	0.078276	0.10748	12/729
Calibration on the 1 st third	0.055528	0.088439	0.19216	8/272
Calibration on the 2 nd third	0.057320	0.076615	0.107630	4/285

Moreover, these little experiments give some interesting indication about the choice of the calibration period. In order to obtain the best thresholds values, a wind class should not be represented in quite negligible proportion. A period presenting a high correlation seems as well to ensure a better selection for the whole period. Logically, this calibration period should also contain the highest wind measurements. Concerning the program, if the maximal observed wind velocity is smaller than the highest chosen wind class, an error message will appear and the program will quit. Indeed, in this case, the program would provide non-optimal threshold values for this last class, leading thus to a less good wind classification from the noise values. For more information, see the matlab code in the appendix B1.

Thus, even if it is a little bit disappointing that the program is not able to select the best general solution considering all the data set, these experiments showed that choosing a calibration according to defined criterion allow ameliorating the success rate of the whole classification.

e) Possible future amelioration in the threshold selection algorithm

There are however also other means in order to increase this success rate. It would be for example maybe possible to ameliorate the selection of these threshold values looking as well as the noise variance patterns. Surprisingly, even if the correlation the correlation is less pronounced between the noise variance and the wind speed, the same procedure considering noise variance values provides success rates that are just a little bit lower (see table 17). Moreover, looking at all the different wind speed classes, the results provided by the both predictor are quite similar. It is so difficult to take directly advantage of the variance value.

Table 17 Success rate of the different predictor for each wind class

Predictor	Wind speed class				
	total	< 0.5	0.5 - 1	1 – 1.5	> 1.5
noisemean	0.67353	0.77704	0.56667	0.67742	0.1875
noisevar	65706	0.71723	0.57143	0.59322	0.2

It should be however possible to further ameliorate the selection comparing where in the data set the both predictors are not able to well predict the right wind speed class. Because the noise mean predictor provides better results, it could be imagined that it serves as first principal predictor. Looking precisely at the noise variance patterns of the wrong predictions made by the noise mean indicator, it could be conceivable to implement an additional filter or criterion based on the noise variance properties. It could so reduce partly these errors.

f) Concluding remarks

After these first tests, it appears that the wind velocity can be successfully derived from the noise values with a resolution of 5 minutes. Indeed, if the best calibration period is chosen, more than 70 % of the total predictions are right. Even if non-optimal threshold values are chosen, the success rate doesn't go below 66% for the whole period. It assesses of the robustness of the selection mechanism.

This success rate must be also analysed in relation with the demanded accuracy of the classification. In this case, it appears that the different wind speed classes are really close together. Surely, on the field such a precision is not needed. It could thus maybe ameliorate in a further way these success rates.

Unfortunately, this test period was too short and presented only low wind velocities. It is a shame because these tests seemed to be able providing quite good results with more data and wider wind ranges. The advantage of the chosen threshold selection mechanism is that it should be theoretically less sensitive to the possible changes in the wind – speed noise relation. For these low wind speeds it appeared that the noise increased quite regularly with the wind speed, but only after a certain wind speed threshold.

Thus, on this stage, these tests provide results that will not be useful on the field, because the observed wind velocities were too small for these 2 usable days of data. Moreover this test are assumed valid for the empty gauge case. The gauge will however never be totally empty, because of the antifreeze liquid that will be present, at least in winter. These tests could be completed thanks to the next testing phase that will install the gauge near to existing meteoswiss stations. These stations also provide wind measurements with 10 minute resolution. However, the anemometer is placed quite high in the air, and probably, the indicated wind velocity will be greater than the one occurring just over the rain gauge orifice.

3.3.2.3 Wind induced noise during rain

To assess this effect, it is first necessary to isolate the noise induced by the rain only. For this purpose, some experiments will be conducted with different initial weights, under constant wind and over the same range of rainfall intensity. In concrete terms, it signifies that a noise-intensity relation will be derived for different initial weights. When this relation will be better understood, it will be tried to isolate the wind effect from the total noise value, when it is rainy.

a) Limitations of the experiment and sprinkler test validation

Concerning the wind, it was unfortunately impossible to find “no wind” conditions, even in the internal garden. But, even if each sequence of measures for a defined weight occurred at a different moment of the day under different wind conditions, it is however assumed that these wind condition differences don’t lead to systematic bias. A reason for that is that these experiments were conducted more times for each weight on different days. Moreover, for the majority of the measured data sets, the duration should be enough long in order to capture different wind conditions. Thus, the wind should rather include an additional noise whose amount depends on the wind characteristics and lead thus to create an additional spread for the intensity-noise relation.

To simulate the range of intensities a sprinkler installation will be used. But before executing these tests, it is primordial to check that this installation is able to reproduce the same noise values than a natural rainfall, otherwise, the observed relations would be maybe no more useful on the field.

Indeed, with the sprinkler installation (see figure 53), the simulated rain present different properties than a natural one, notably concerning the size and the trajectory of the rain drops. Because it doesn’t correspond to the ideal “no wind” conditions, it was also checked that the drops falling none vertically on the housing and in the bucket don’t create additional noise.

All these effects were successfully controlled; the results and discussion of these sprinkler validation tests are presented in the appendix A.



Figure 53 The sprinkler installation.

b) Assessment of the weight influence

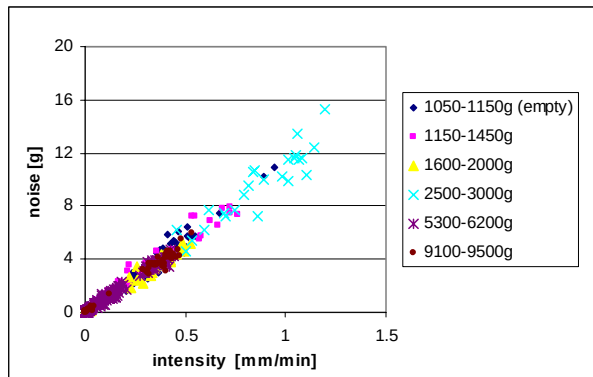


Figure 54 Noise – rainfall intensity relation for different initial ranges of weight

Analyzing separately each set of data, it appears that the relation noise-intensity seems to depend from the initial weight. Indeed, the trend lines computed for each weight range seem to present light different behaviours among the different weights as visible on the figure 55. The table 18 presents the different obtained equations. It was necessary to first correct the indicated intensity because of the warming phase of the data logger (more information in chapter 3.1.1.2).

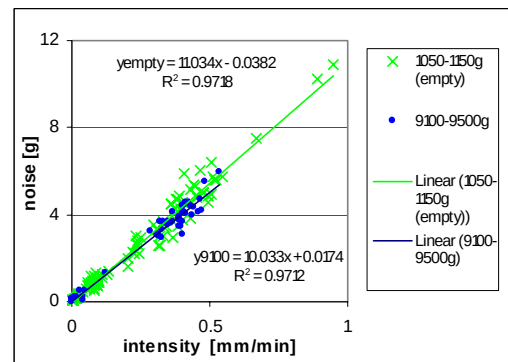


Figure 55 Trend lines for the empty and 9 kg cases.

Table 18 The different derived linear equations for each initial weight. The 2500-3000g trend line is not represented because small intensities were not available for this data set.

Range of weight	Equation of the linear trend line $y = ax + b$	R^2	Number of samples	Equation of the linear trend line $y = ax + b$ (not corrected values)
1050 – 1150g (empty)	$y = 11.034x - 0.0382$	0.9718	118	$y = 10.282x + 0.0766$
1150-1450g	$y = 10.762x + 0.0377$	0.9708	84	$y = 10.753x + 0.0367$
1600-2000g	$y = 9.9178x + 0.0234$	0.9694	63	$y = 9.9178x + 0.0234$
5300-6200g	$y = 10.147x + 0.0247$	0.9872	411	$y = 10.157x + 0.0216$
9100-9500g	$y = 10.033x + 0.0174$	0.9712	58	$y = 10.036x + 0.0165$

It appears thus that, increasing the initial weight present in the bucket, the noise induced by the rain particle tends to decrease. It is in fact quite comprehensible, because a higher water level in the rain gauge bucket can better absorb the impact caused by the rain drops. On this way the weights measurements become less noisy. It seems as well that after a certain amount of water present in the gauge, the absorption of the rain drops shocks is not more dramatically increased. Indeed, the difference in the trend lines between 5300 g and 9100 g is not so big. On the contrary, for the first ranges of weights, the differences are bigger.

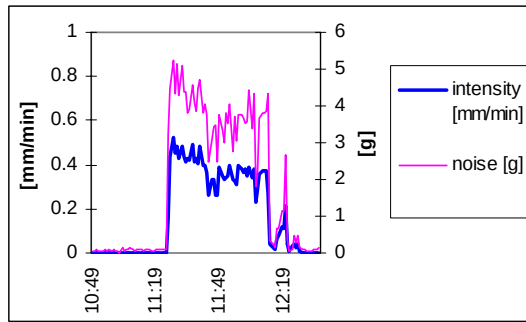


Figure 56 noise before and during a rainfall.

A very important feature of this relation is the spread. Indeed, as visible on the figure 56, the noise induced by the rain amounts to some multiples of the one induced by the wind. Thus, even if the different R^2 coefficients are very good for the different derived linear relations, it appears already that it would be quite impossible to obtain values about the wind velocities when it is raining. Indeed the slightest spread in this linear relation changes the noise values in domains that correspond to really high wind velocities.

It was however optimistically (or naively according to the point of view) tried to isolate the wind effect from the noise response during rainfall.

c) Assessment of the wind during rainfall from the noise values.

The chosen procedure to isolate the wind effect on the noise during rainfall is very easy. A simplified model assuming that the noise depends only from the wind and the rainfall intensity is adopted. Thanks to the known noise – rainfall intensity relation, the noise values are corrected when it is rainy.

A problem with this procedure is that the wind is also present during rainfall and thus affects also the noise – rainfall intensity relation. On this way the corrections also delete in a certain part the wind effect on noise. But, optimistically it could be thought that the spread around the linear trend could in a certain part reflect the discrepancies with the mean wind conditions that occurred during the rainfall.

Looking at the total predominance of the rainfall intensity on the noise response, it seems absolutely necessary to define the noise – rainfall intensity relation for each considered rainfall. Otherwise, the slightest bias affecting the noise – rainfall relation would provide corrected noise values that are unusable.

This procedure was applied for the sprinkler experiment represented in the figure 56. Looking at the corrected noise values (see figure 57), it appears directly that they are quite unusable in order to assess the wind velocity during this sprinkler test. The oscillations are indeed great and provide sometimes noise values that were never observed with the sole influence of the wind. Even if the mean over 5 minutes is considered for the noise values, it still provides unusable values. The same procedure was applied for rainfall event presenting smaller intensities, but without more success.

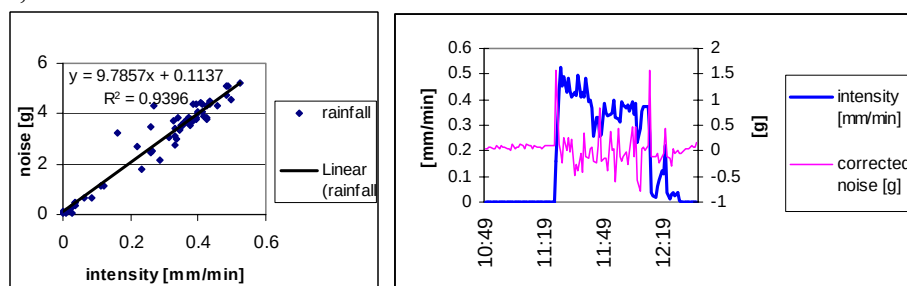


Figure 57 Left: assessment of the noise – intensity relation for the rainfall event. Right: correction of the noise values according to the derived relation.

d) Concluding remarks

It appears thus that during rainfall, the noise characteristics don't allow to derive the wind velocity. The obtained results are totally insufficient and prove that the made assumptions were false. The spread in the rainfall intensity – noise relation can therefore not be caused only by the wind characteristics. Thus, different other parameters should explain this spread. It is difficult to assess surely what kind of characteristics could explain this spread because no information is available on the different filter algorithms that provide the noise data. However, probably that the rainfall variance occurring inside the considered minute plays an important role in the noise response. Indeed the tests made about the ground noise attest of a quite oscillating behaviour. These oscillations were also observed in other tests during rainfall, where also a great increase of the raw noise was followed by an also impressive decrease. These observations seem to indicate that a short rainfall pulse creates more weight variations than a regular one and could thus explain the spread of the intensity – noise relation.

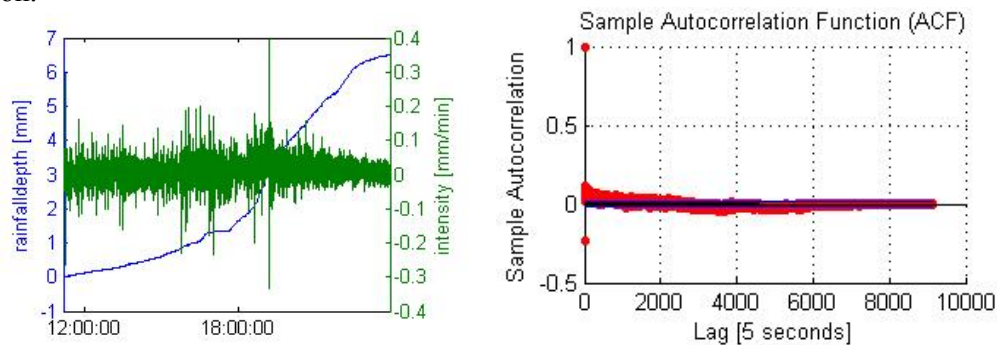


Figure 58 Left: intensity derived from raw weight measurements. A quite symmetrical behaviour attests of the oscillations of the raw weight. Right: These oscillations are confirmed looking at the negative autocorrelation coefficient that was computed for the first lag of 5 seconds.

Moreover, some other limitations reduce the chance to obtain wind indication from the noise values. Indeed, the wind can induce some catching errors from the gauge, mainly “for rains with a larger fraction of smaller drops and higher wind speeds” [4]

With such conditions it is probable that the gauge underestimates a little bit the real precipitation. The wind seems thus to affect the noise also in an indirect way, changing sometimes the amount of rainfall caught by the rain gauge. Regarding at the big difference in the noise responses to rainfall and wind, it could therefore occur that high wind periods correspond to moments where the noise was smaller because of the possible catching errors.

In closing, the best indication about the wind conditions that occur during rainfall is probably provided by the noise characteristics obtained just before the rainfall beginning. If wind corrections on the indicated intensity want to be properly applied, an anemometer is thus absolutely necessary.

3.4. General appreciation of the rain gauge

Globally, the rain gauge provided always very satisfactory results concerning the rainfall intensity.

On all the different tests made, only rare and very small deformations of the rainfall were observed. Moreover, these deformations didn't lead to under- or overestimation of the total amount of rainfall. The WMO conducted a lot of accurate laboratory tests that confirm the very high accuracy of the indicated intensity. Some rough tests just confirmed these excellent results concerning the "counting" errors. Unfortunately the made also by the WMO comparing the performance of different rain gauges in field conditions are not yet available. It is therefore difficult to become an idea about the possible "catching" errors of the gauge. The next test phases in Payerne and Zermatt will allow comparisons with other gauges. However, during all this first test phase, the gauge was always able to provide consistent intensity data with a delay of 1 minute over all different climatic conditions.

The single problem concerning the intensity was linked to the data logger. Indeed, after each restart of the rain gauge, the data logger seems to need a warming phase, whose characteristics and duration are not well known, before indicating correct intensities. This phase seems rather to be linked with rainfall features, because even if the gauge was plugged for days, the first recorded rainfalls are not satisfactory caught. It should however not create too big problems for the field work. Indeed, firstly the gauge will not be too frequently disconnected. Secondly, even within this warming phase, the pattern of the rainfall corresponds to the one that would be indicated by correct intensities. The assessment of the small time scale variance is thus not endangered. Concerning the calibration of the radar data, the observed discrepancies should not lead to big problems because they are rather at 1 minute scale relevant. The radar provides information with 5 minute resolution case. Anyway, there is always the possibility to recalculate the correct intensities, thanks to the weight measurements that are also sent with the 1 minute resolution data. But on this way, some filter mechanism of the data could disappear.

The experiments conducted about the temperature provide also satisfactory results. The accuracy of the extern air temperature sensor is very good. Because this sensor will be better protected from the radiations for the next testing phases, the provided measurements should be ameliorated. On the contrary, a constant shift of about 0.6 [deg cels] affects the intern sensor. It is however not so important because this temperature serves to the gauge, mainly for "internal" work. It was thus illustrated that the gauge was always able to account for the temperature – weight dependence and that on this way no wrong rainfall should be "created".

The tests concerning the noise indicated that there are good chances to obtain a reliable wind assessment method from the noise values. However, further tests should be conduct in order to extend the range of observed wind and initial weights. If these tests are made, it would be important to pay attention at the height of the anemometer relatively to the rain gauge orifice. On the contrary, these tests indicated that the attempt to derivate wind speed thanks to the noise patterns during rainfall would be similar as looking for a needle in a haystack. The better indication of wind speed in case of rainfall is thus probably given by the noise values just before the beginning of the rain.

Concerning the GPRS transmission, this first test phase indicated that it was reliable. Only some minutes are missing or contain empty information. Roughly estimated, it concerns less than 0.2 % of the total data. The data logger presents an important property. If the strength of the GPRS signal decreases, it is able to store and send again the data when the signal becomes

stronger. Because the logger has a memory able to store the data for 1 month, the risk to loose measurements is rather weak. However, the data logger is not able to send the newest measurements after a long time without communication. Indeed, in this case it begins to resent all the historical messages to the server. It lasts for many hours. This feature is not very pleasant, because on this way, it is difficult to control that the gauge works well after an installation. To check that the installation was successful, it is thus necessary to use the additional cable allowing to dialogue with the data logger from a computer. Asking for the last measurements allows assessing if the gauge works properly.

The installation of the gauge is easy and doesn't require a lot of time and tools. However, the solutions should always be adapted to the chosen place and could thus require more time or persons. For each situation, it should be possible to obtain a perfect horizontality of the gauge because the adjustable screw bolts allow a great breathing space. Moreover, the need of maintenance is really reduced. The bucket can store up to 12 kilos of water, which corresponds to 600 mm rainfall. In the reality, because of evaporation, the gauge should be able to record quite more precipitation before that the emptying manipulation is necessary.

The dialogue with the rain gauge or the data logger thanks to the terminal is not user friendly and presents some times quite strange characteristics. It is unfortunately the single way to change different parameters or to install the simcard. However, with a little bit practice the most important commands are easy usable.

Concerning the resolution of 5 seconds, the measurements are quite noisy and thus unusable. Even if treated absolute weight values (WABS) are available each 25 and 35 seconds, they can not provide a smaller resolution of intensity, because the other weight values (WCOMP...) are updated only each minute. These other weight values present probably the last stage of the filter mechanism. This not exploitable data is however not a critic of the gauge, because it was explicitly mentioned that this 5 seconds resolution measurements are not a commercial application. This resolution was moreover very useful and indispensable to better understand the working style of the gauge.

In closing, this rain gauge should provide 1 minute data of high quality without high supervision needs. The whole system presented furthermore a high reliability during the all duration of this first test phase.

4. Data analysis

In this chapter, the data provided by the gauge will be analysed with scaling based methods. This analysis is inspired by the one described by Marani in the both papers: “on the correlation structure of continuous and discrete point rainfall” [5] and “non-power-law-scale properties of rainfall in space and time” [6]. Before starting with the analysis, these both papers will be first roughly and non-exhaustively summarized. Secondly, some preliminary tests are made on the available data in order to conduct the analysis in the more appropriate way. Particularly, it will be assessed if the 5 second resolution data should be used despite of its noisy behaviour. Indeed, for statistical analysis this high resolution is very interesting. Finally, the results conducted on different data sets will be presented. Indeed, for comparison purposes, sprinkler tests and two rainfall events presenting different behaviour are analyzed. Because the testing phase was too often interrupted in order to obtain long and good set of data, the historical rainfall measured in Zermatt will also be used.

4.1 General points

In the last 40 years, numerous researchers studied the « relationship between the statistical characteristic of rainfall measured at relatively long aggregation scale and the properties observed at shorter aggregation scales ». [5] The motivation of this research is easy comprehensible. Indeed, if a relation is found, the meteorological data at larger aggregation scale (for example daily data) could be exploited in order to become information about rainfall properties at smaller aggregation scales. Thus the daily data, which is already from a long time available in numerous regions, could for example be used to generate thanks for example to downscaling approaches, hourly resolution data that is absolutely required for a lot of different hydrologic purposes.

Different scientists found a power law structure over the different range of aggregation of the rainfall statistical moment. Marco Marani showed however that this power law scaling can't hold over all the aggregation scales. He made detailed research about the variance patterns of the rainfall depth aggregated at different scales. It showed theoretically that, for aggregation intervals T tending to 0 seconds, the variance pattern behaves as T^2 . Moreover, for large aggregation scales, the variance behaves as T^β with $1 \leq \beta < 2$. The value of β depends on the correlation structure of the observed rainfall. For the case with a finite memory, β should equal 1. On the contrary, if the rainfall presents an infinite memory, β should be greater than 1. Because two different power law scaling are available for very small and large aggregation scales, it implies the existence of a transition regime, linking these two distinct parts. This transition regime is thus inadequately represented by a power law, because the exponent β should decrease from 2 (in the inner regime) to $1 \leq \beta < 2$ (see figure 59).

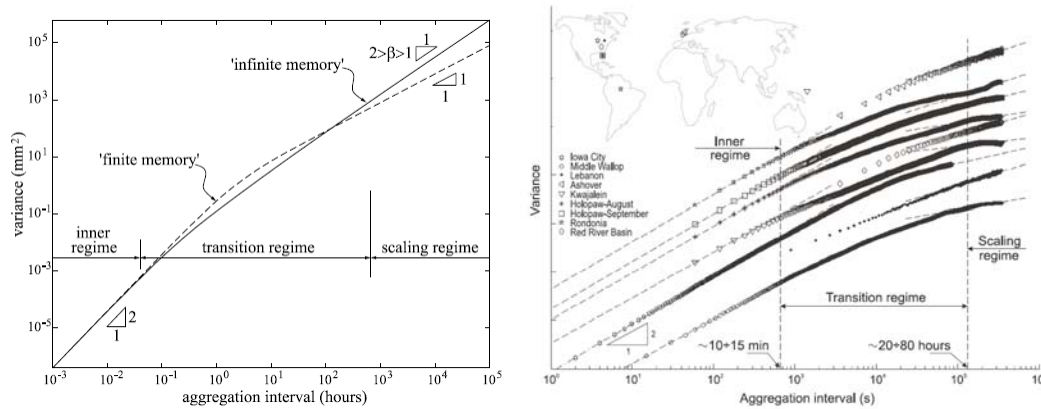


Figure 59 Left: theoretical variance curve of the aggregated rainfall process as a function of the aggregation interval. Right: experimental variance. Source: [5] and [6]

Marani conducted different analysis and observations and concluded that « in the wide set of different locations, climates and observation devices considered, the transition regime is located at the temporal scales of usual hydrologic interest.» [6] So, the use of “temporal downscaling [...] based on power law scaling assumption may result into gross extrapolation errors due to the presence of the transition regime.” [6] Thus, in order to avoid these errors, the downscaling should take into account the different observed variance patterns among the aggregation scales.

4.2. Preliminary tests

In this part the results obtained with the both available resolution will be presented. Indeed, the noise value could be usable because the white noise contained in this data should disappear with increasing aggregation scales. Moreover, different calculation of the variance for each aggregation scale will be tested. These results will allow selecting the data set and the calculation method that provide the most relevant results.

4.2.1 Influence of the data resolution

It was possible to compare the results provided by these both resolutions for the same data set. Indeed, in the first case the raw weights indicated each 5 seconds were used to compute the intensity and the accumulated rainfall depth. In the second case, the treated intensity value provided each minute served to compute the accumulated rainfall depth. The figure 60 allows a good comparison of the both set of data.

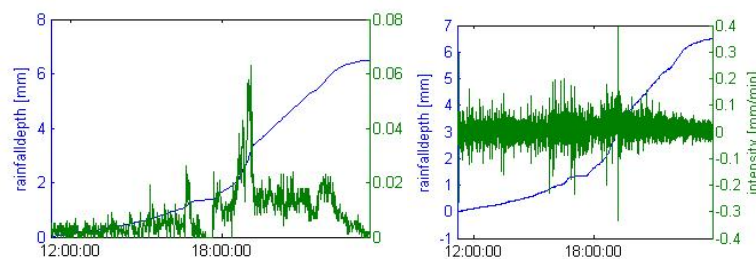


Figure 60 Accumulated rainfall depth and intensity. Left: 1 minute resolution. Right: 5 seconds resolution

It appears directly, that the noise is very high in the case of the 5 second resolution. Indeed the thus computed intensities don't make sense. They have a quite oscillating behaviour over a wide range of intensities and present as well negative values. Logically, these features play an important role, looking at the derived sample autocorrelation function (See figure 61).

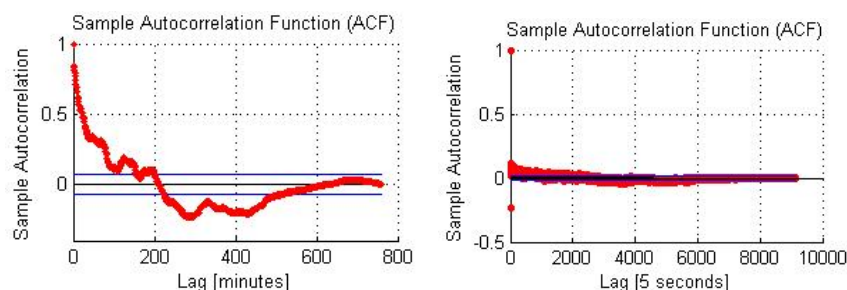


Figure 61 Autocorrelation function. Left: 1 minute resolution. Right: 5 seconds resolution

In the 5 seconds case, the quite negative autocorrelation obtained for the 5 seconds lag attests of the big oscillations of the weight. Comparing with the 1 minute autocorrelation, it appears as well that a great part of the correlation structure was removed. For the first lags, autocorrelation coefficients above 0.2 are not visible, and the negative correlation coefficients obtained for the case with 1 minute resolution almost disappeared.

Comparing the both variance patterns obtained over different aggregation scales (see figure 62,) it appears that the results are quite similar. It is indeed quite logical, because the noise is assumed to be random, and should thus disappear with increasing aggregation scales. Some little discrepancies between the two variance values could maybe provide from the filter algorithms that sometimes provide other intensities than the difference of weight.

Looking at aggregation scales smaller than the smallest one provided with 1 minute resolution data (2 minutes), it appears that the variance provided by the 5 seconds resolution is not directly usable below aggregation scales of about 1 minute. Through its oscillating behaviour, the noise logically tends to increase the variance for small aggregation scales. Thus, the use of the 5 seconds resolution data don't provide quite additional interesting results that justify the quite bigger amount of time needed to calculate the variance patterns.

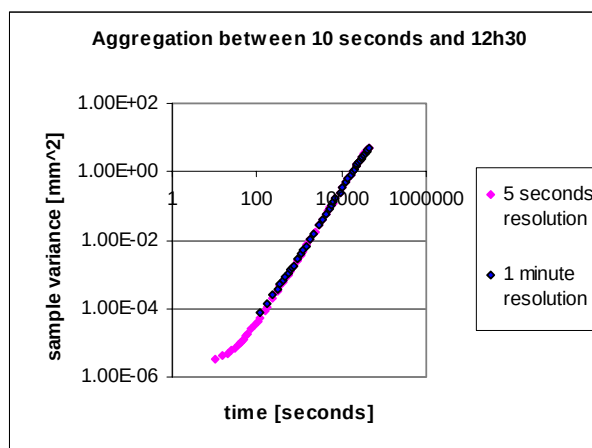


Figure 62 Sample variance among aggregation scales from 10 seconds to 12h30.

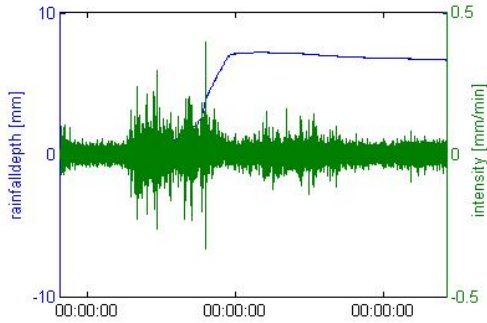


Figure 63 Accumulated rainfall depth and intensity. 5 seconds resolution data.

Moreover, the use of data set coming from raw values involves additional problems. Indeed, on the contrary to the data provided with treated intensity values, the raw weight data are affected by the evaporation, leading thus to accumulated rainfall depths that are not any more usable for statistical test, because it logically decreases with the time (see figure 63).

4.2.2 Influence of the calculation of the scale variance

Two different ways of calculating the variance were tested. On the first manner, overlapping between the different rainfall depth values was allowed, leading thus to more numerous intermediate variances than in the case where overlapping was avoided. For the both cases, the final variance just considers the mean of all these intermediate values (see figure 64 as well as the matlab code in the appendix B1).

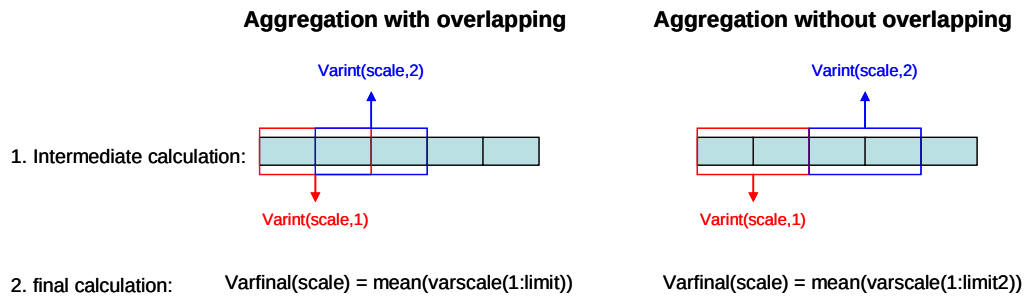


Figure 64 The both ways tested to calculate the scale variance. In this example the scale equals logically 2.

Looking at the results provided by the both ways, it appears that the overlapping of rainfall depth provides more convenient final scale variances. Indeed, for large aggregation scales, the case without overlapping begins to not consider all the data set, leading thus to quite strange behaviour of the general pattern (see figure 65). On the contrary, the overlapping case always allows considering the whole data set. For smaller aggregation scales the results are however similar. Thus, in order to exploit all the data set, the case with overlapping will be chosen for calculating the variance pattern among the aggregation scales.

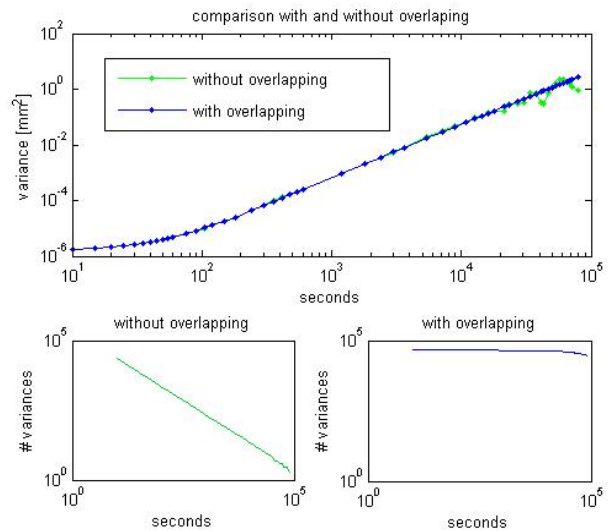


Figure 65 Above: comparison of the variance curves over the different aggregation scales. Below: number of considered intermediate variances for each aggregation scale.

4.3. Results

In this chapter, different experiments involving always longer data set will be presented. Moreover, it was tried to select event presenting different memory properties in order to compare these results with the observations and the theory from Marani.

4.3.1 Sprinkler tests

It is particularly interesting to conduct this analysis on sprinkler tests. They should indeed represent a field of constant rainfall intensity affected by a noise that is assumed random. To check this assumption the sample autocorrelation was computed (see figure 66).

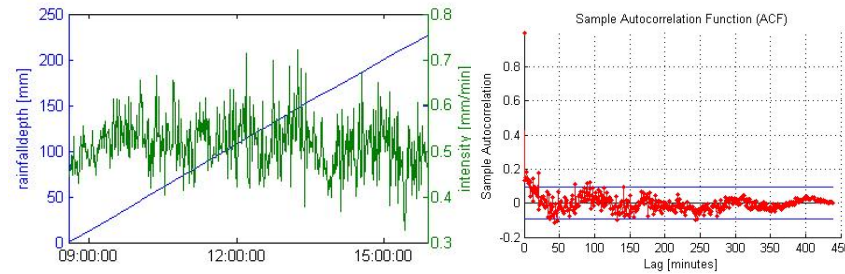


Figure 66 Sprinkler test. Left: intensity and cumulated rainfall depth. Right: ACF.

It appears that the sprinkler test present a little memory process of maximal 10 minutes where the autocorrelation coefficients regularly decrease. However, they are always below 0.2 attesting thus of the weakness of the memory process. Different factors such as changing wind properties or variations of the water tap flow could explain this little memory signal.

The whole sprinkler test could thus be interpreted as an artificial prolongation of the really small scale time variance that occurs during a rainfall. Therefore, this data set should extend indefinitely the inner regime mentioned by Marco Marani. The obtained results confirmed this assumption; a power-law fitting provides indeed a β value very close to 2 (see figure 67). However, it seems that for the smallest aggregation scales the fit with the power law presents some discrepancies. In order to check this impression only the variance aggregated up to 10 minutes were considered. It confirmed that for this domain, a power law presenting a smaller β value (1.8) provides a better fit (see figure 68).

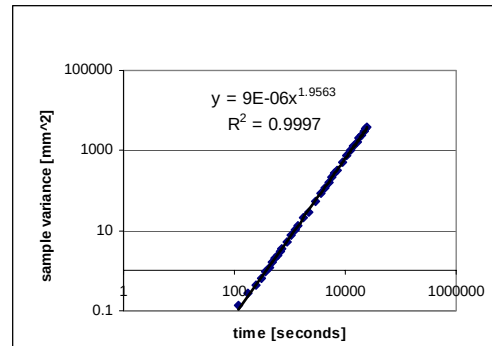


Figure 67 sample variance among aggregation scales from 2 minutes to 7 hours.

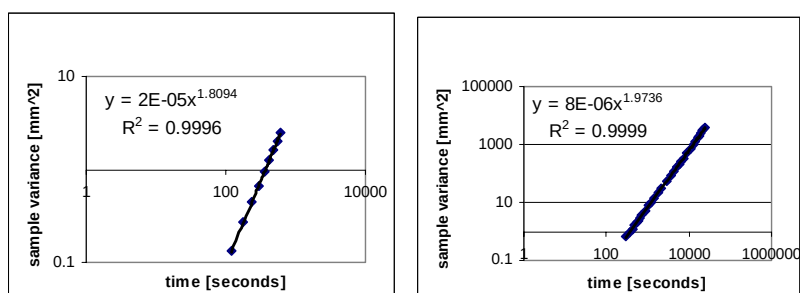


Figure 68 Left: sample variance among aggregation scales from 2 minutes to 10 minutes. Right: from 10 minutes to 7 hours

This result is really strange, because it doesn't respect the observational and theoretical conclusions of Marani concerning the inner regime.

In order to check if this strange effect is maybe related only to this sprinkler experiment, another shorter sprinkler test with less intensity was also conducted. Looking at the autocorrelation coefficients characterising this sprinkler test, it seems that for this second sprinkler test no memory effects are present (see figure 69).

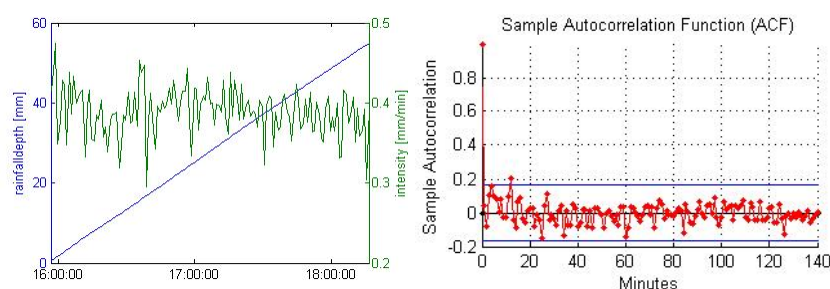


Figure 69 Second sprinkler test. Left: intensity and cumulated rainfall depth. Right: ACF.

Looking at the values obtained for the different scale variances, it appears that exactly the same behaviour as before is present among the different aggregation scales. Also for the small aggregations, the fit with a power law provides a β value smaller than 2. The only difference is in the absolute values of the sample variance. It is a little bit smaller, but it is logical looking at the weaker intensity (see figure 70).

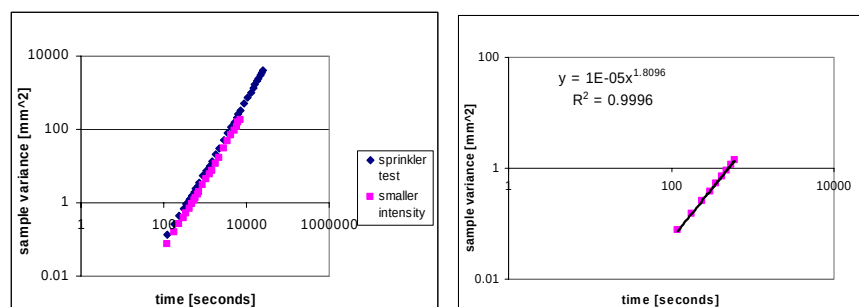


Figure 70 Left: comparison of the sample variance of the two sprinkler tests. Right: zoom on the second test, from 2 to 10 minutes.

A more complete discussion concerning this strange effect will be made at the end of the different analysed set of data.

4.3.2 Tests on short “isolated” rainfall events

During the test phase, the gauge captured different types of rainfall events. For this test, two different quite long events presenting short memory and long memory effects were selected.

4.3.2.1 Short memory event

This selected rainfall presented quite interesting characteristics. Different peaks of varying intensity occurred during the day. It provided about 35 mm of water with a record intensity peak of 1.2 [mm/min]. Logically, this event doesn't present long memory behaviour, the different peaks seem independent from each other. They could correspond to the arrival of rain clusters (see figure 71).

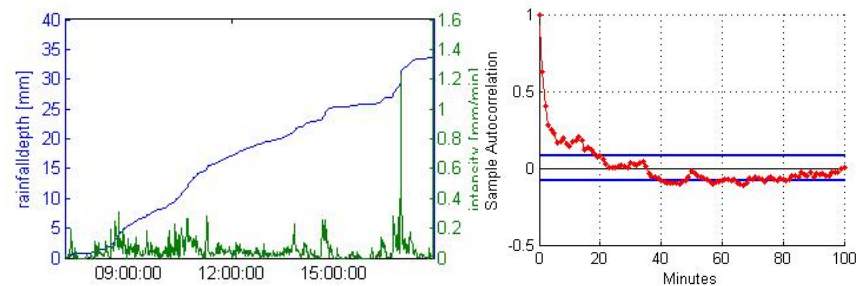


Figure 71 Left: intensity and cumulated rainfall depth. Right: ACF.

The scaling based analysis provided the variance patterns visible in the figure 72. At the first sight, an inner and transition regime is difficult to recognize. It seems however that the same strange effects as before observed are present for the smallest aggregations scales. Moreover, for the biggest aggregation scales, it as well seems that the slope of the variance pattern becomes a little bit steeper.

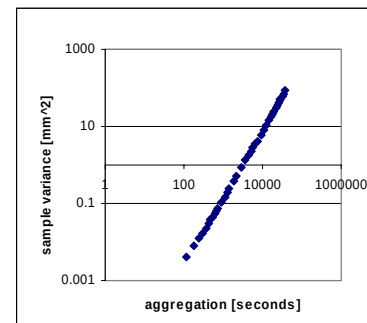


Figure 72 Variance curve for the aggregated rainfall process. Aggregation scales between 2 minutes and 2 hours.

These first observations were confirmed fitting different power law functions to the variance curve among different groups of aggregation scale. For the aggregation between 2 and 10 minutes a β value of 1.59 was fitted.

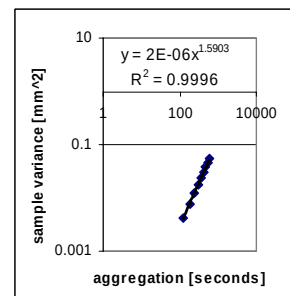


Figure 73 Aggregation between 2 and 10 minutes

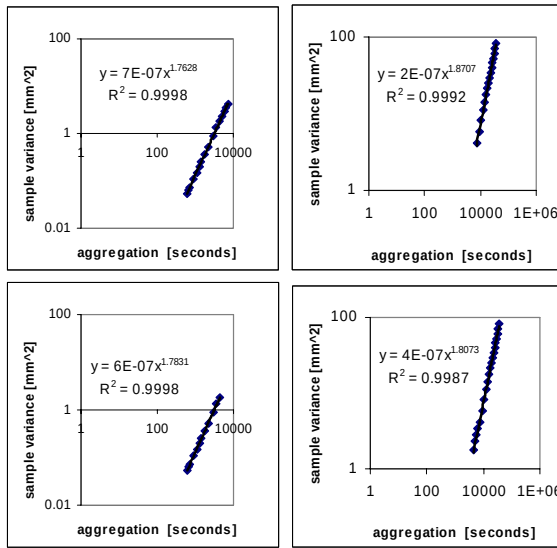


Figure 74 Above: between 10 min and 2 hours and between 2 and 10 hours. Below: between 10 minutes and 1h15 and between 1h15 and 10 hours.

Concerning the bigger aggregation scales, it is important to relativize the obtained β values. However, according to the choice of these grouped aggregation scales, quite different β values can be obtained (see figure 74). It is thus very important to first consider the whole aggregation scale, and not look only at the small “selections” of this set, otherwise wrong interpretations could be made. It is in fact logical that different β values are obtained, because the length of the selected data set is not so big and thus β should be sensitive to the “spread” of the variance pattern. The different period selected provided however β values that already seem to increase among the aggregation scale. Before to discuss this behaviour, the longer memory event will be analyzed.

4.3.2.2 Longer memory event

The selected rainfall event presented quite constant behaviour during a day. About 12 hours of small intensities provided a total amount of about 6 mm water. Logically, in this case the memory is quite longer. There is also a significant negative autocorrelation after the lag of 200 minutes. Probably, at this lag, the computation leading to the different autocorrelation coefficients begin to take into account the smaller and bigger part of the intensity patterns (see figure 75).

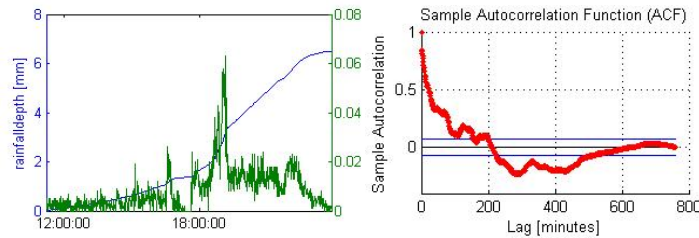


Figure 75 Left: intensity and cumulated rainfall depth. Right: ACF.

The same analysis was conducted and provided the results visible in the figure 76. After the first visual impression, it appears that this variance pattern corresponds better to the one “expected”, even if the same strange behaviour still affect the “inner regime”. Indeed, a decrease of the slope seems to be present for the highest aggregation scales. It could thus correspond to the description of the transition regime made by Marani. Logically, regarding at the different β values (see figure 77), this decrease is quite small, because the highest available aggregation scale amounts to 12h30. It corresponds thus to only a part of the transition regime. According to Marani this transition could extend up to aggregation scales of about 80 hours.

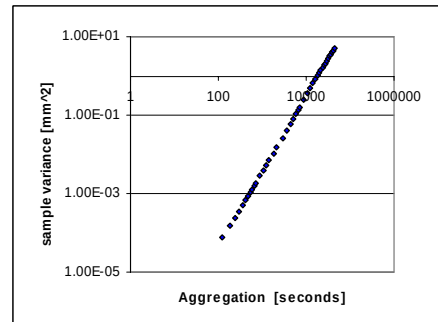


Figure 76 Aggregation scales between 2 minutes and 12h30.

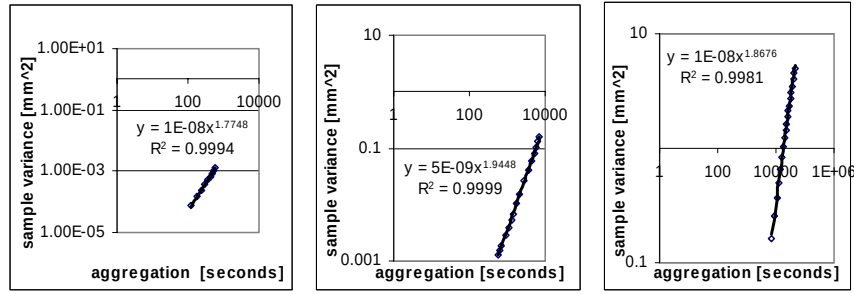


Figure 77 Zoom and power law fitting on different aggregation scale ranges. Left: between 2 and 10 minutes. Middle: between 10 minutes and 2 hours. Right: between 2 hours and 12h30

Finally, these tests of selected rainfall event with different structure provided results that are difficult to exploit. Indeed, especially for the short memory case, the results were quite strange. Moreover, because of the short length of the record, only small aggregation scales could be derived. Thus, it is possible that the observed general tendencies (increase of β in the short memory case and decrease for the longer memory case) are only small discrepancies that wouldn't play a big role if quite bigger aggregation scale would be assessed. However these experiments allow to again remark the same strange features affecting the smallest aggregation scales.

A comparison between the two types of memory effect is difficult to do, because theoretically the influence of the memory should be visible in the asymptotic behaviour of the aggregation scales belonging to the scaling regime.

It is also difficult to comment these results because such tests with so short period of measurement are not mentioned in the paper of Marani. On the contrary, quite longer data set are used. These data sets present also logically numerous periods where no rain occur.

4.3.3 Tests on short “extended” rainfall event

In order to have data set, that could be a little bit more similar to the one used by Marani, the selected rainfall events are extended to longer observation period. It will allow exploring further the behaviour of the variance in the assumed transition regime, thanks to aggregation scales of 32h30 and 62h30.

4.3.3.1 The “short memory” event

Extending the first irregular intensity event, it appears that the autocorrelation structure changes quite dramatically. Indeed, a memory effect is visible up to lag of 500 minutes, even if almost all the values are below 0.5. This change is logical, because now the rain is no more “isolated” and thus the memory effect of the whole rain process becomes more visible. Logically, these about 500 minutes of correlation effect correspond to the rain duration. The smallest peaks in the decrease of the autocorrelation coefficient could attest of the correlation that occurred during the transit of one rain cluster of the storm.

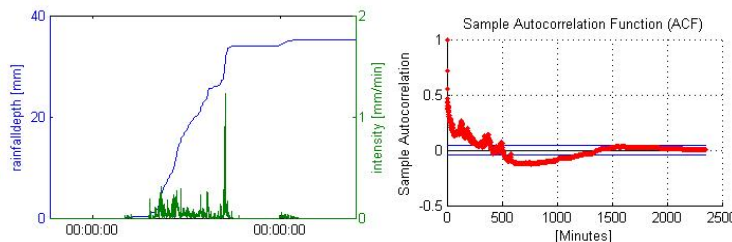


Figure 78 Left: intensity and cumulated rainfall depth. Right: ACF.

Looking at the variance among the different aggregation scales (see figure 79), about the same behaviour as for the selected case is observed. Indeed the slope seems to regularly slightly increase. However, for the highest aggregation scale a big decrease of the slope is available. This increase could thus just be “temporary”. Looking more carefully at the figure representing the variance pattern obtained by the different data set of Marani (see figure 59), it appears also that sometimes some “temporary” increase of the slope occurs. This “special” feature represents thus not inevitably a contradiction of the Marani observations. On the contrary, Marani itself wrote that “the shape of the variance curve in the transition regime is not always “smooth” as it depends on the shape of the autocorrelation characterizing rainfall”. [6] As for the selected case, the “inner regime” presents a β value of 1.59. It represents this time a contradiction with the Marani observations.

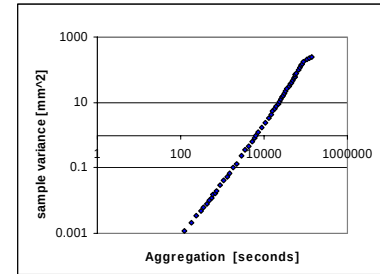


Figure 79 Aggregation scales between 2 minutes and 32h30.

4.3.3.2 The longer memory event

With an extension of the before considered event to about 62h30, logically, the patterns of the autocorrelation function change as well. During about the first 500 minutes a regularly decrease up to 0 of the autocorrelation coefficients occurs. For the first lag, very high values of these coefficients are available (see figure 80).

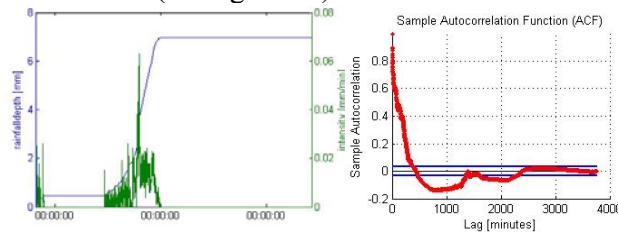


Figure 80 Left: intensity and cumulated rainfall depth. Right: ACF.

Again, the analysis made over this extended set provided similar results as before (see figure 81). It shows however an accelerated decrease of the slope for the highest variance scales, where a power law fit provided a β value of 1.22. As for the non-extended case, a β value smaller than 2 was obtained for the “inner regime”.

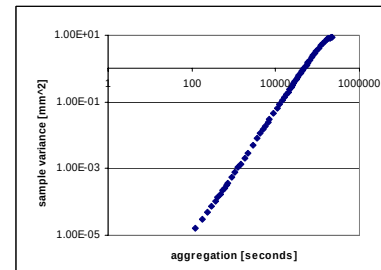


Figure 81 Aggregation scales between 2 minutes and 62h30.

Finally, looking at the result concerning the extending set of data, there are rather encouraging signs. Indeed, with data sets that are a little bit more comparable with the one used by Marani, for the both considered events, it seems that already a tendency for decreasing slope of the variance pattern exists inside the transition regime. Apparently the scaling regime, characterized by a constant power law behaviour of the highest aggregation scales, was never reached. It is also difficult to assess the influence of the memory process. Moreover, the two set of data didn’t present the same length and it could thus skew a comparison.

4.3.4 Tests on long historic data

In order to have set of data that should be in all features comparable to the one of Marco Marani, some historical data of the meteoswiss station in Zermatt was downloaded. The resolution amounts to 10 minutes. All the months of December and July of the last 10 years were put together, in order to create two different time series supposed to present different behaviour looking at the memory. Indeed, it was assumed that in summer convective events presenting high intensity and short duration would rather occur. These characteristics should lead to short memory. On the contrary, longer memory should characterize the December months, when rather frontal rain presenting long duration and low intensity occurs.

4.3.4.1. July time series

According to the attempts, the selection of 10 of July months provided an autocorrelation function that decreases rapidly. After about 75 lag of 10 minutes, the coefficients fluctuate around 0 (see figure 82). The scale based analysis was conducted on the whole data set, allowing obtaining a maximal aggregation period of about 10 months.

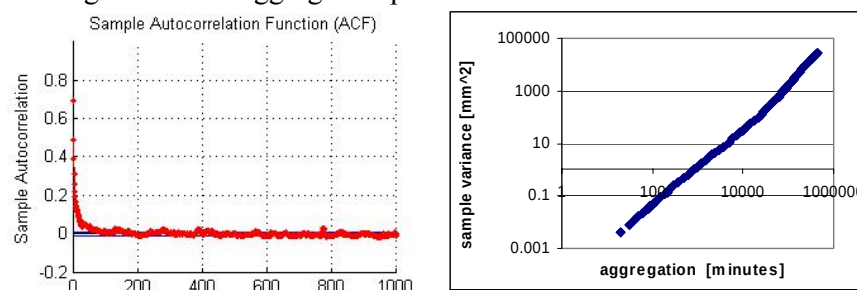


Figure 82 Left: ACF. Right Aggregation scales between 20 minutes and 10 months

The analysis of the variance patterns illustrated different effects. First, for the first lags, the before observed decrease seems not to be present. Indeed the two power law fits obtained for the aggregation scale considering 20 minutes to 1 hour and the 1 hour to 10 hours (see figure 83) provide quite similar β values. Moreover these β values are quite small, but with 20 minutes aggregation, the “inner regime” should be already “behind”.

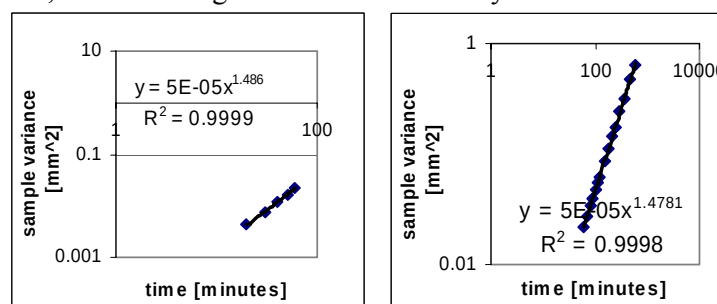


Figure 83 Left: sample variance among aggregation scales from 20 min to 1 hour. Right: 1 to 10 hours.

For the aggregation scale bigger than 10 hours, it seems that the slope characterising the variance patterns presents a tendency to decrease. It was confirmed checking at the provided β values that presented as well a decreasing behaviour. However, for very high aggregation scales, this slope begins again to increase. This last increase feature is in fact quite logical. Indeed, it should be not too much aggregated, otherwise the variance will begin to mix events of different sorts. It seems to be here as well the case, even if data coming always from the same month was chosen. It is not so surprisingly, because the rain patterns can be different from one year to another and as well inside a single month. Indeed, it would be totally

possible that frontal rain occurs as well in July. For these reasons it is necessary to not too much aggregate, and the variance pattern will be analysed up to 15 days, which however represents a quite big aggregation scale (see figure 84). Considering only these “smaller” aggregation scales, the results look quite better. Indeed, at the first sight, a zone where a change in the slope occurs is well visible. The power law fit based on the interval 100 hours – 15 days indicated a β value from about 1.42. Thus, comparing with the before obtained β value of 1.48 for the variances between 1 and 10 hours, the presence of the transition regime is confirmed, even if the change stays small.

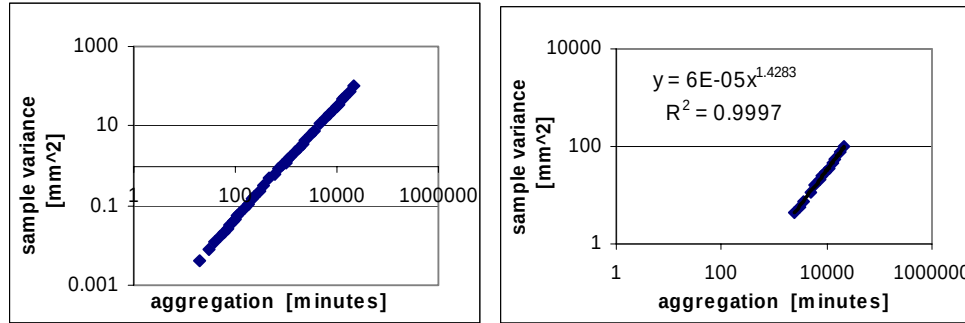


Figure 84 Left: the new considered aggregation range. Right: Interval between 100 hours and 15 days.

4.3.4.2 December time series

Similar tests were conducted for the time series containing 10 December months. Again the considered variance curve was reduced to aggregation scales not bigger than 15 days (see figure 85).

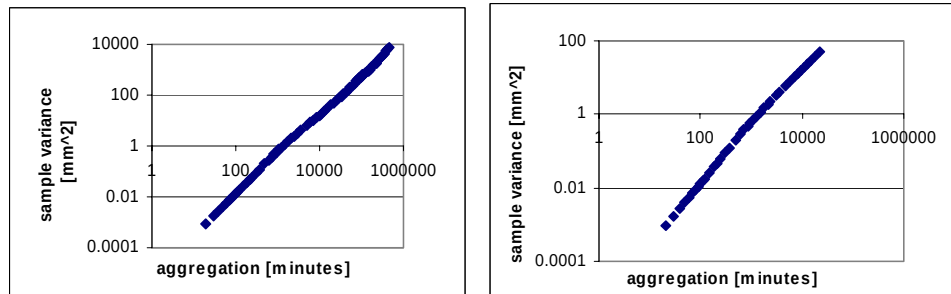


Figure 85 Left: the whole aggregation range (up to 10 months) Right: Only up to 25 days.

About the same variance patterns among the aggregation scales than in the July case are visible. However, with this time series, a first increase of the slope after the first aggregation scale occurs. The β value goes from 1.62 to 1.73. After that, the transition regime is well visible and for the scaling regime a β value of 1.43 is obtained (see figure 86).

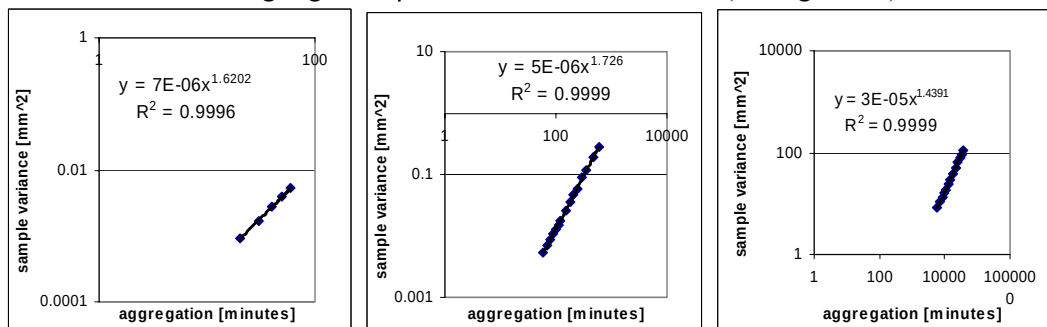


Figure 86 Different intervals of the whole aggregation range. Left: 20 minutes to 1 hour. Middle: 1 hour to 10 hours. Right: 100 hours to 15 days.

The β value fitted for the highest aggregation scales is quite similar to the one obtained for the month of July. It appears a little bit surprisingly, considering the first assumptions about the memory process that should be longer for the month of December. However, looking at the autocorrelation function of this time series (see figure 87), large differences with the one from July are not visible. The decrease is less rapid for the smallest lags, but also after about 100 lags of 10 minutes, the coefficients begin fluctuating around 0. Thus the small difference between the β values fitted for the highest aggregations scales of the both time series is not absolutely an anomaly.

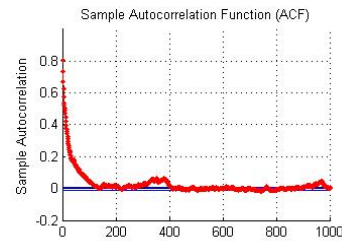


Figure 87 ACF for the December time series.

4.4 concluding remarks

The obtained results correspond only partly to the theoretical and observational behaviour described by Marani. For the data set probably more similar than the one used by Marani, the presence of a transition regime at usual scale of hydrological interest was also found. The other set of data, provided sometimes similar results, but the interpretations were quite hazardous, because of the great uncertainties considering the relevance of the used data set for these comparisons with the results from Marani.

However a point is very problematic. Indeed, the slope increase of the variance curve constantly recorded for all set of data after the first computed aggregation scales seems quite unnatural. The biggest clue to pretend that it is possibly an artefact is provided by the both sprinkler tests. After this first increase the slope was stabilized at a value from 2, illustrating thus the validity of the Marani's observations considering the inner regime. Indeed, these sprinkler tests should represent an extension of the "inner regime" because it is supposed that the very small temporal scale variance that could occur during a rainfall is reproduced.

It would be worth to take time to analyse what could be the cause of this increase. Artefacts created by the rain gauge can be excluded, because the long historical data measured by another rain gauge presents the same features. These long time series allowed also excluding an artefact produced by too short data sets. Thus, very probably the matlab code computes wrong calculations. It was unfortunately impossible to check that surely, because no information on the variance calculation was available on the paper from Marani. Another version of computation that didn't select the mean of all the variances was also tried, but the same effects appeared again. If it can be demonstrated that this effect comes from inadequate calculations, it would be thus worth to reconsider the 5 seconds resolution data. Indeed a part of the observed "too high" variance for the smallest aggregations scale could come from this computation artefact and not only from the noisy values. However, the undesirable effect of the evaporation should still be removed.

It would be maybe interesting to go deeper in these considerations, looking for example at the behaviour of the scaling of all the order of moments. Marani looked indeed in [6] only at the variance and the second order moment characteristics among the scales. Quick calculations showed that indeed all the moments are concerned with this changing behaviour during the transition period (see figure 88).

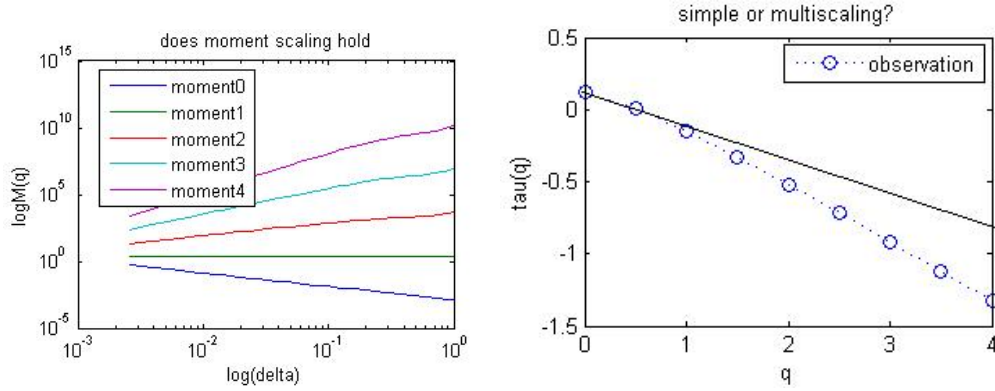


Figure 88 Left: Plot of the different moments among the aggregation scale. A delta value of 10^0 corresponds to the whole aggregated time series. The smallest value of delta corresponds to 2 minutes aggregation Right: the behaviour of the exponent $\tau(q)$ among the different order of moments q .

This example is not very good because it considers the extended long memory event. It is indeed not sure that the use of this short data set is relevant. On the contrary, it seems to be rather a “strange” data set, looking at the obtained behaviour of the exponent $\tau(q)$ among the different order of moment. Indeed, in the most data set presenting multi scaling, the “observation points” were rather above the straight line. Computing this graph could thus maybe provide a kind of control about the validity of the used data set. Other indications about the validity could surely be found analyzing the autocorrelation function. The small data sets tend to often present some negative autocorrelation after a defined number of lags. Such patterns are probably not to find in longer data sets.

In closing, it would also probably be interesting to assess if all the different moments present an inner, a transition and a scaling regime. Moreover, it would be probably indispensable to check that the aggregation scales at which these different regimes appear are always located at the same place for the all different moments and that the observed changes are similar. Otherwise, if the multi scaling is assessed only thanks to parameters that take into account the behaviour of the $\tau(q)$ exponents, it could maybe lead to supplementary extrapolation errors.

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Internet: General information about the Apunch Project:
 <http://www.swiss-experiment.ch/index.php/APUNCH:Home>

Appendix

A. Sprinkler tests validation

A1. Effect of non similar rain drop properties

One reason of inadequate sprinkler tests could be that, when small intensities are simulated, it is rather thanks to isolated large drops that are falling intermittently on the gauge. On the contrary, under natural condition such intensities could also be obtained through small water drops that fall regularly and frequently in the gauge. These different drop structures could create different noise response, leading thus to problems for the interpretation of the results. Looking at the relation noise – intensity for sprinkler tests and natural conditions, it seems that, even if it is not exactly the same processes, the induced noise are quite comparable and that the sprinkler tests are able to provide rain that present plausible features concerning the induced noise (see figure 89)

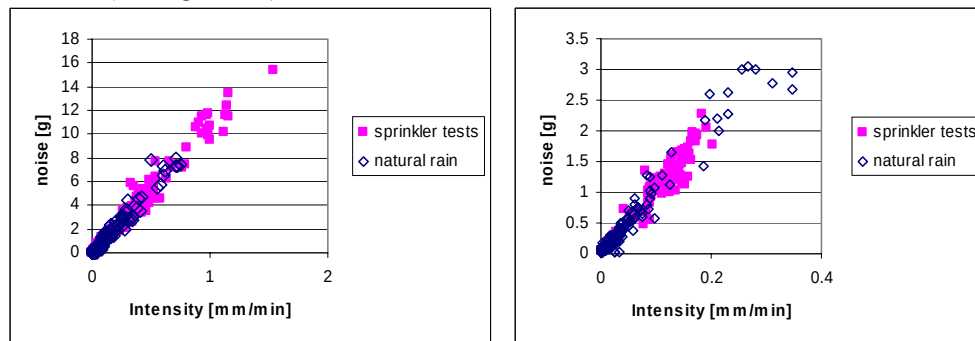


Figure 89 Left: comparison of the noise induced by “sprinkler” and “natural” rain. Right: zoom on smaller intensities.

A2. Effect of rain particle falling on the housing

Under real “no wind” conditions, the rainfall particle should fall quite vertically in the gauge. With this type of sprinkler test, it is quite impossible to obtain drop particles falling vertically in the gauge, so that a lot of particles are hitting the housing with non-vertical trajectories. It could thus induce an additional noise. This effect was assessed covering the orifice of the gauge, while sprinkler tests still occurred, trying thus to separate the effect of these drops hitting the housing. On a second phase, the “sprinkler” rain was stopped and the orifice was again opened. It appears that the noise induced by the hitting of the rain drop on the housing is quite weak (see figure 90). In this case, the biggest noise values were to find when the orifice was open, because the dynamic pressure fluctuations engendered by the wind again occurred. Thus it seems that the housing protects very well the gauge.

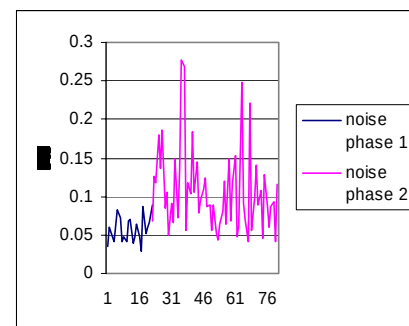


Figure 90 Noise pattern comparison.

B. Matlab codes

B1. Prediction of wind speed

```
%% PROGRAM FOR EXPLOITING THE NOISE VALUES IN ORDER TO OBTAIN WIND
%% INFORMATION

%% Because for this experiment the solar panel couldn't provide enough energy,
%% some lacks are present in the wind data. Thus first find these lacks and
%% eliminate the corresponding noise values provided by the rain gauge.

clear all

%% == 1. Download the data ==

[WS WD time] = textread('filename.txt','%f %f %f','headerlines',0);
[time number precipimin temp WABS precip5m noise] = textread('filename.txt','%f %f %f %f %f %f
%f','headerlines',0);

%% == 2. data treatment ==
%% It eliminates the "wrong" measurements of the anemometer as well
%% as the noise measurements related to the wrong wind measurements.

ngauge = length(WABS);
limit = fix(ngauge/5);

c = 0;
for i = 1:limit
    if WS(i) ~= 0 && WD(i) ~= 0 % wrong measurement
        c = c+1;
        WStreated(c) = WS(i);
        WDtreated(c) = WD(i);
        noisetreated((((c-1)*5)+1):5*c) = noise((((i-1)*5)+1):5*i);
    end
end

%% == 3. Computation of different parameters ==

%% computation of 5 minute resolution noise data
for j=1:c
    noisemean5treated(j) = mean(noisetreated((((j-1)*5)+1):5*j));
    noisevar5treated(j) = var(noisetreated((((j-1)*5)+1):5*j));
end

%% computation of direction and speed changes
for k = 2:c
    directionchange(k) = WDtreated(k)-WDtreated(k-1);
    if directionchange(k) > 180
        directionchange(k) = 360 - WDtreated(k) + WDtreated(k-1);
    end
    if directionchange(k) < -180
        directionchange(k) = 360 - WDtreated(k-1) + WDtreated(k);
    end
    directionchange(k)=abs(directionchange(k));
    windchange(k) = WStreated(k) - WStreated(k-1);
end

directionchange(1) = 0;
windchange(1) = 0;

%% computation of the different cross correlations
crosscorWnoisemean = corrcoef(WStreated,noisemean5treated);
crosscorWnoisevar = corrcoef(WStreated,noisevar5treated);
crosscorWDchangenoisemean = corrcoef(directionchange,noisemean5treated);
crosscorWDchangenoisevar = corrcoef(directionchange,noisevar5treated);
crosscorWSchangenoisemean = corrcoef(windchange,noisemean5treated);
crosscorWSchangenoisevar = corrcoef(windchange,noisevar5treated);

%% == 4. Best threshold selection procedure ==

% definition of the different wind classes
wind_range = [0.5, 1, 1.5]
```

```

% control of the choosen wind classes
if max(wind_range) > max(WStreated);
    display('attention the maximal wind range speed is greater than the maximal');
    display('observed one. On this way the program would provide wrong results,');
    display('press enter to quit');
    pause;
    break;
end

%% selection of the best noise value used to separate the different wind ranges
textnoise = ['noiseall'; 'noise_05'; 'noise_10']
textwind = ['windall'; 'wind_05'; 'wind_10']
noisemean5treatednew = noisemean5treated;
WStreatednew = WStreated;

for i=1:length(wind_range)
    namenoise = [textnoise(i,:) '.txt'];
    namewind = [textwind(i,:) '.txt'];
    %% save in a text file each noise and wind values corresponding to the current wind range
    csvwrite(namenoise, noisemean5treatednew);
    csvwrite(namewind, WStreatednew);

    [wind_obs] = textread(namewind, '%f');
    wind_obs2 = wind_obs;

    %separation of the wind velocities that are greater than the current wind range
    wind_obs(wind_obs2>=wind_range(i))=1;
    wind_obs(wind_obs2<wind_range(i))=0;

    % choice of threshold => building a ROC
    limit_min= min(noisemean5treated);
    limit_max= max(noisemean5treated);
    % 300 step
    step=(limit_max-limit_min)/299;
    threshold = limit_min:step:limit_max;
    nb_thres=length(threshold);

    for j=1:nb_thres
        %- Prediction of the wind velocity according to the noise values -
        % all the values over the threshold => bigger than wind_range(i)
        % all the values under the threshold => smaller than wind_range(i)
        windspeed_pred = textread(namenoise, '%f');
        windspeed_pred2 = windspeed_pred;

        windspeed_pred(windspeed_pred2>=threshold(j))=1;    % wind larger
        windspeed_pred(windspeed_pred2<threshold(j))=0;    % wind smaller

        % Computation of the success indicators of the prediction
        % a = true positive (observed and predicted)
        A = wind_obs.*windspeed_pred;
        a(j)=sum(A(:));

        % d = true negative (non-observed and non-predicted)
        A=(1-wind_obs).*(1-windspeed_pred);
        d(j)=sum(A(:));

        % c = false positive (error type I) (observed and non-predicted)
        A=wind_obs.*(1-windspeed_pred);
        c(j)=sum(A(:));

        % b = false negative (error type II) (non-observed and predicted)
        A=(1-wind_obs).*windspeed_pred;
        b(j)=sum(A(:));

        % Security, if the denominators are == 0
        % this security is the reason why the program provides wrong results if a wind range
        % is greater than the maximal observed wind velocity. Only 0 values would be present
        % and thus for this range the sens and spec would not be new defined.
        % the program would thus display the same values than for the case i-1.
        if a(j)+c(j) ~= 0 & d(j)+b(j) ~= 0
            % sensitivity (proportion of positives cases correctly predicted)
            sens(j)=a(j)/(a(j)+c(j));
            % specificity (proportion of negative cases correctly predicted)
            spec(j)=d(j)/(d(j)+b(j));
        end
        % selection of the best threshold: maximize the sensitivity and the specificity
        sum_sens_spec(j) = sens(j)+spec(j);
    end
end

```

```

[best_value(i), indice(i)] = max(sum_sens_spec);
best_threshold(i) = threshold(indice(i));
sensivity(i) = sens(indice(i));
specificty(i) = spec(indice(i));

%%remove the data that are smaller than the i-th wind speed range,
%%in order to evitate less good selection of threshold.
WStreatednew = WStreatednew(noisemean5treatednew>best_threshold(i));
noisemean5treatednew = noisemean5treatednew(noisemean5treatednew>best_threshold(i));

%----- ROC -----
%sensitivity against specificity!
figure(22)
subplot(1,length(wind_range),i)
plot(spec,sens, '.');
xlabel('specifity'); ylabel('sensitivity');
hold('on')
%straight line (y=1-x) indicates the limit with the "random model"
fplot('1-x',[0 1], 'r');
hold('off');
end

%% == 5. Classification of the wind thanks to the best threshold value ==

for m=1:length(noisemean5treated)
    if noisemean5treated(m) < best_threshold(1)
        wind_calculated(m) = 0.5;
    end
    if noisemean5treated(m) >= best_threshold(1) && noisemean5treated(m) < best_threshold(2)
        wind_calculated(m) = 1;
    end
    if noisemean5treated(m) >= best_threshold(2) && noisemean5treated(m) < best_threshold(3)
        wind_calculated(m) = 1.5;
    end
    if noisemean5treated(m) >= best_threshold(3)
        wind_calculated(m) = 2;
    end
end

%% == 6. Computation of the classification success ==
%% It separates as well the good from the wrong predictions

success = 0;
for m=1:length(WStreated)
    if (wind_calculated(m) - WStreated(m) >= 0 && wind_calculated(m) - WStreated(m)<= 0.5 )
        success = success + 1;
        WStreatedright(m) = WStreated(m);
        WStreatedwrong(m) = NaN;
    else
        WStreatedwrong(m) = WStreated(m);
        WStreatedright(m) = NaN;
    end
end

successrate = success/length(WStreated);

%% == 7. Plots and other small calculations ==
...

```

B2. Scaling based data analysis

```
%% PROGRAM FOR BUILDING THE VARIANCE PATTERN AMONG DIFFERENT AGGREGATION
%% SCALES

clear all

%% == 1. Download and read data, derivation of useful values ==
%% Attention to well pre-process the file in excel: replace all the "-" by "999" and define
%% the format cell of the date column in the excel sheet as number with 10 decimals

[date, intensity1min, rainfall, sensetemp, WABS, STATID, DEV, interntime, WRAW, bweight,
cweight, exttemp, NOISE] = textread('sprinklerwithoutbias.txt', '%f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f', 'headerlines', 4);

n=length(WABS);
MATLABDate = x2mdate(date, 0); %Converts Excel serial date number to MATLAB serial date number

%% Calculation accumulated rainfall depth [mm] and intensity [mm/min] from the different WRAW
%% values (5 seconds resolution with noise)
% for j=2:n
%   rainfalldepth(j-1) = (WRAW(j) - WRAW(1))/20;
%   intensity(j-1) = ((WRAW(j) - WRAW(j-1))/20)*12;
%   x(j-1) = MATLABDate(j-1);
% end

%% Calculation accumulated rainfall depth [mm] and intensity [mm/min] from the different
%% indicated intensity values. (1 minute resolution without noise)
c=0;
for j=1:n
    if (intensity1min(j) ~= 999);
        c=c+1;
        intensity(c)=intensity1min(j);
        rainfalldepth(c) = sum(intensity);
        x(c)= MATLABDate(j);
    end
end

intensity=intensity';
rainfalldepth = rainfalldepth';
x=x';

%% plot of the accumulated rainfall depth and the intensity
figure(1)
[haxes depth int] = plotyy(x,rainfalldepth,x,intensity)
axes(haxes(1))
ylabel('rainfalldepth [mm]')
datetick('x',13)
xlim([x(1) x(length(x))])
axes(haxes(2))
% axis ij %if you want to inverse this axe...
ylabel('intensity [mm/min]')
datetick('x',13)
xlim([x(1) x(length(x))])

%% plot of the autocorrelation function
[ACF,Lags,Bounds] = autocorr(intensity,length(intensity)-1);
figure(2)
autocorr(intensity,length(intensity)-1);

% == 2. Statistical analysis sample variance at different aggregation
scales ==

scales = [2,3,4,5,6,7,8,9,10,11,12,15,18,21,24,30,36,48,60.....];

%% x axes for 5 seconds resolution data
% xaxes = 5.*scales;
%% x axes for 1 minute resolution data
xaxes = 60.*scales
```

```

%calculation of the sample variance for each aggregation time

%==== case without overlapping ====
for i=1:length(scales)
    limit(i) = fix((length(rainfalldepth)/scales(i))); %fix a limit in order to avoid that the
    program reads values that don't exist
    begin = 0;
    for nseparate=1:limit(i)
        varintermediate(i,nseparate) = var(rainfalldepth((begin+1):nseparate*scales(i)));
        begin = nseparate*scales(i);
    end
    varscale(i) = mean(varintermediate(i,1:limit(i)));
end

%% ==== case with overlapping ====
for j=1:length(scales)
    limit2(j)=length(rainfalldepth)-(scales(j)+1);

    for noverlap=1:limit2(j)
        varintermediate2(j,noverlap) = var(rainfalldepth(noverlap:(noverlap+(scales(j)-1))));
    end
    varscale2(j) = mean(varintermediate2(j,1:limit2(j)));
end

% == 3. Tests on the moment scaling ==

To=length(rainfalldepth);
T=scales;

mom_end=4*2+1;

for pas=1:mom_end
    for k=1:length(T);
        delta(k) = T(k)/To;
        limit3(k)=length(rainfalldepth)-(T(k)+1);
        for no=1:limit3(k)
            A(no)=1/(T(k))*(sum(rainfalldepth(no:(no+(T(k)-1))))).^(pas/2));
        end
        moment(pas,k)=mean(A(:));
    end
end

%% plot of the different moment => does the moment scaling hold?
figure(3)
loglog(delta,moment(1,:),delta,moment(2,:),delta,moment(3,:),delta,moment(4,:),delta,moment(5,
:));
legend('moment0','moment1','moment2','moment3','moment4')
ylabel('logM(q)')
xlabel('log(delta)')
title('does moment scaling hold');

%% plot of the different tau(q) values => simple or multiscaling?
for i=1:9
    % selecting the first aggregation scale is an approximation of the limit when delta tends
    % to 0.
    value(i) = log(moment(i,1))/log(delta(1))
end

xaxes2=[0:0.5:4]
figure(4)
plot(xaxes2,value,'o');
legend('observation')
ylabel('tau(q)')
xlabel('q')
title('simple or multiscaling?');

```